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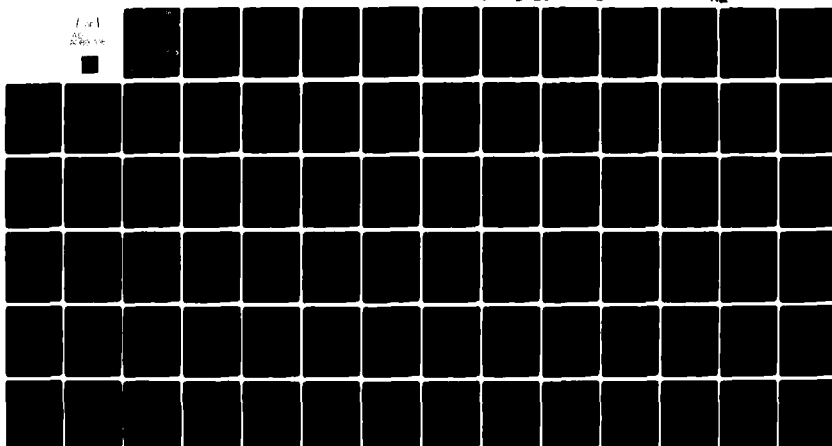
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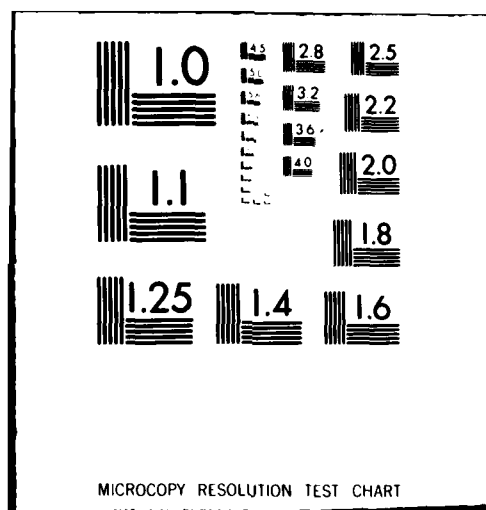
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**THE
REFORGER 76
MSI TEST**

June 1980

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Approved For Public Release; Distribution Unlimited


AIR WEATHER SERVICE (MAC)
Scott AFB, Illinois 62225


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This technical publication has been reviewed and is approved for publication.


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FOR THE COMMANDER


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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) REFORGER is an annual exercise to test the ability of US forces to support NATO commitments. During the 1976 exercise, AWS tested a new means of providing war/contingency support, i.e., objectively produced mission success indicators (MSIs). An MSI is the probability that a mission will succeed. It provides the decision maker a single number expressing the impact of weather on a mission. During REFORGER 76, AWS provided MSIs for four scenarios or types of missions: Cobra/TOW against a tank, 105mm gun against a tank, close air (over)		

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Continued from Block #19:

Simulated Mission Success Indicator
STEPR

TAILOR
Transnormalized Regression Probability

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support, and helicopter assault. In the 3 months prior to the exercise, AWS expended nearly five man years in development effort. This report details the events leading to this effort, the models developed, the support provided, forecast verification, customer feedback and future efforts. The chapters are essentially a compilation of reports submitted by AWS units participating in the exercise.

PREFACE

AWS tested a new means of providing war/contingency support during the REFORGER 76 mobility exercise. This new means was through the use of objectively produced mission success indicators (MSIs), the probability of mission success. This report details the events leading to this effort, the support provided by AWS, the models developed, forecast verification, customer feedback, and conclusions and recommendations. It was originally to be published in early 1977 but was delayed by disagreements on the reasons for some of the results and by other projects. The effort produced several lessons learned, so it is important that it be documented, and the recommendations staffed. This note applies to all AWS personnel because it provides information on a future way of providing AWS support, a way that will impact the majority of AWS personnel.

When it was decided in June 1976, to test the MSI concept during REFORGER 76, only three months remained for development and testing. During these three months, nearly five manyears of development work and a large training program were accomplished. During the exercise, SWOs spent many hours providing special support and gathering verification data.

This limited MSI test demonstrated that MSI products have potential to increase combat effectiveness, and that this methodology could benefit AWS in its capability to support war/contingencies in an automated mode. This effort also provided insight into the problems that could occur during this support. AWS must deal with the problems documented in this note before proceeding with the MSI support concept.

This note is a compilation of reports submitted by several AWS units on individual aspects of this test; consequently, the format may vary slightly between chapters. The author has taken liberties with arrangement and wording of the individual reports and has added material. However, this report essentially consists of the reports submitted by AFGWC/DOY (Lt Col Allen R. Coburn), AFGWC/WPA (Lt Col Billie E. Grubbs), and AWS/DOA (Maj Arthur C. Kyle). The latter incorporated material from the 2nd Weather Wing After Action Interim Report. In addition, three USAF Environmental Technical Applications Center (USAFETAC) Reports are incorporated as chapters. These USAFETAC reports are Report 8065C (Capt Gary E. O'Connor), Report 7966 (Murray J. Young), and Report 8065A (REV) (Murray J. Young). Finally, extracts are included from Capt Boehm's "Optimal Decisions Through Mission Success Indicators," a paper presented at the 7th Technical Exchange Conference. Acknowledgements are made only at the beginning of chapters.

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Chapter 1

INTRODUCTION

During REFORGER 76*, the Air Weather Service (AWS) tested a new means of providing war/contingency support under realistic conditions. This means was through the use of objectively produced mission success indicators (MSIs). An MSI is the probability that a mission will succeed. It provides the decision maker a single number which expresses the effect of weather on a mission option. Other information, such as weapon characteristics and enemy defenses, may be blended with weather to give an integrated MSI that is an efficient decision aid. The choice between alternate routes, weapons, and tactics is aided by considering the MSI for each option.

Three types of weather MSIs were used to support REFORGER 76. The forecast MSIs (FMSI) were used on a day-to-day basis to make go/no go decisions. The climatological MSIs (CMSI) provided the average prospect of a mission succeeding at a specified location during a given time of year and time of day. They are used to develop plans that consider weather limitations. Simulated MSIs (SMSI), the third type, show the effect of weather on mission accomplishment, attrition, and resource requirements. SMSIs can be used to determine the desirability of various force structures, tactics, and weapon systems, as well as to assess the weather limitations on enemy operations.

MSIs were provided during REFORGER 76 for four scenarios: Cobra helicopter/TOW missile against a tank, 105mm gun against a tank, close air support, and helicopter air assault. FMSIs were produced for 114 grid points, twice a day, for every six hours out to 36 hours. CMSIs were produced by a new method, i.e., relating climatology to geographic features. SMSIs were produced using an analytic formula.

Development efforts for REFORGER 76 support did not begin until June 1976. In only three months the entire MSI system was developed. During the three months prior to the exercise, nearly five man-years of development work was accomplished.

This report details events leading to this effort, the support provided by AWS, the models developed, forecast verification, customer feedback, and conclusions drawn.

*Return of Forces to Germany, a mobility exercise. Details in para 2.2

Chapter 2*

BACKGROUND

2.1. Events Leading to REFORGER 76 Support

Brig General Berry W. Rowe, AWS Commander, during a command visit to Europe in August 1975, discussed AWS support to Army forces in Europe with General Blanchard, Commander-in-Chief United States Army Europe (CINCUSAREUR). General Blanchard was very interested in weather support and the capabilities of AWS. He requested that General Rowe return to Europe in the spring of 1976 and brief him on AWS's plans for improving their support to USAREUR. After returning to the CONUS, General Rowe held discussions on Air Force Global Weather Central (AFGWC) support for military exercises or limited war contingencies with Col Herbert Million, AFGWC/CC. Col Million offered to redistribute five manpower spaces in AFGWC to form a nucleus for a Contingency Response Capability (CRC). When not actually involved in supporting an operational contingency, these people would accomplish several other functions. First, as operations plans coordinators, they would help major command (MAJCOM) staff weather officers (SWOs) formulate weather support concepts for planned exercises. This would be accomplished by normal staff action and temporary duty to the MAJCOM planning location. The goal was that every operations plan would have attached to the weather section a set of preformatted requests (IAW AWSR 105-18) ready for almost immediate execution. Second, the CRC cell would actively assist other production division work centers at AFGWC during contingencies. If necessary, people from this cell could deploy to a contingency location to help establish support procedures and to provide expertise to the deployed SWO. This might be particularly desirable or necessary for contingencies for which no plan existed prior to its occurrence. AFGWC suggested that the concept be tested in a major Tactical Air/Army exercise. AFGWC asked for an AWS policy statement that field units use centralized products in their routine support activities. This would shift manpower resources away from scheduled forecaster aid production in favor of more tailored support and train units to request and use centralized support. Support of a REFORGER exercise was proposed as a test of these concepts.

General Rowe directed that a Tactical Weather Support Concept Conference be convened (September 1975) to unify AWS efforts in the tactical support area. Colonel Gayikian, AWS Chief of Staff, emphasized this idea in his charge to the conferees when he said that AWS must "insure tactical weather support concepts are unified, timely, adequate, and flexible and satisfy identifiable customers in potential situations." At this conference were representatives of all the wings, the HQ DCSs, AFGWC Operations Division (DO) (Col Stephens and Lt Col Coburn), Combined Arms Combat Development Activity (CACDA) SWO (Lt Col, then Maj, McDonald), and United States Army Intelligence Center and School (USAICS) SWO (Lt Col, now retired, Owens). AFGWC was tasked to develop methods to satisfy unique forecast requirements for the tactical environment and to make forecasts available for transmission to the field.

Major McDonald visited AFGWC in October 1975. Army support, in general, was discussed, and it was agreed that the idea of applying probability forecasting techniques to Army support from a centralized facility was a realistic goal for AFGWC planners. He pointed out to Lt Col Coburn that Army operations are very diverse: some decisions are made in the field using real-time data while other decisions are made at much higher levels. He indicated it would be possible to postulate certain types of decision points and criteria, but pointed out the need to limit the size of the effort and to obtain help from all players supporting the Army. An objective was needed and some success would have to be demonstrated. The conclusion was reached that a large, recurring exercise should be selected; one which would allow some time to prepare, organize players, plan the support, and execute the plans. The concepts for providing Army Support were set forth in the "Concept of Centralized Support for Tactical Army Forces" (APPENDIX A), drafted in October 1975 by the AFGWC/Operations Division. In December 1975, the U.S. Army CACDA reviewed the initial concept for furnishing MSI products to the tactical commanders and suggested that a formal briefing to the Joint Working Group (JWG), cochaired by AWS and USARCACDA, be provided in January 1976 at USAICS. The "AFGWC Concept of Operations" was briefed to the AWS Staff in early January 1976, approved, and established as the "AWS Concept of Operations." The AWS concept was briefed to the Commander USAICS, Brig Gen Kelly, who approved the concept and recommended that AWS test the concept during REFORGER 76. The JWG tasked AFGWC to implement this concept. A plan was developed by AFGWC and sent to AWS. At the same time, Lt Col Coburn began to coordinate the scenarios with TRADOC and the development of computer software with USAFETAC/DO, AWS Aerospace Sciences (DN), and AFGWC Production Division. In

*This chapter is basically Reference 2.

April 1976, since estimates of development costs were high, HQ AWS decided there was a need to brief General Blanchard on the plan before committing the resources necessary for completion of the project.

In May 1976, Col Molla, AWS Vice-Commander, was accompanied to Europe by Col Kennedy, Lt Col Coburn, and Maj Chesley from AWS/DO. Col Coburn presented a tailored briefing on the MSI concept to CINCUSAREUR, General Blanchard, similar in scope to the earlier briefing given at USAICS. It was pointed out in this briefing that the increasingly sophisticated weaponry to be used on the battlefield in future Army operations merited a new approach to giving weather support to Army decision makers. The MSI as a specialized mission tailored product was described to the CINC along with test objectives of command/control, communications, and centralized weather support. This concept was accepted favorably by Gen Blanchard, and AWS proceeded to develop and test a decision assistance prototype package for REFORGER 76.

2.2. The Exercise

REFORGER is the name applied to a United States Commander-in-Chief Europe (USCINCEUR) sponsored mobility deployment of dual base CONUS ground forces to Europe and their subsequent employment. When it was decided, during the mid-60s, to decrease the number of military forces assigned to NATO and to defend the Federal Republic of Germany, the U.S. Government agreed to sponsor an annual, mobility exercise into Germany. While in Europe, the deployed forces participate in training exercises with U.S. Air Force Europe (USAFE) and U.S. Army forces in central Germany. During REFORGER 76, the deployed forces participated in two Army training exercises which required tactical air support: GORDIAN SHIELD and LARES TEAM. Air support for the first was provided under COLD FIRE, an Allied Forces Central Europe offensive air exercise. CRESTED CAP forces and permanently assigned USAFE tactical aircraft conducted exercise operations from their deployed and home stations for both GORDIAN SHIELD and LARES TEAM. The general areas of operations were in the Northern and Central Army Groups/Allied Air Force Central Europe areas of responsibility (central and northern Federal Republic of Germany). The Army training exercises were planned to test and improve procedures and techniques for receiving, equipping, and assembling augmentation forces from the CONUS for tactical employment in Europe. In addition, the exercises were designed to provide in-country, combined arms training for the exercise forces, with emphasis on improved standardization and interoperability of Tactical Air Command (TAC) AIR, Army aviation, Army ground forces, allied forces, and Special Forces such as electronic warfare and chemical, biological, radiological (CBR) warfare. The scenarios in the training exercises included tests of the Automated Army Air Application, e.g., visual flight rules (VFR), instrument flight rules (IFR), paradrops, side looking air radar operation, close air support, and aerial resupply operations. The ground operations included anti-armor, armor, CBR, engineer, air defense, and signal operations.

2.3. Weather Support and the Army's Intelligence Preparation of the Battlefield

Since the 1973 Middle East War, military leaders have reevaluated offensive and defensive doctrine. New ideas, doctrine, and tactics have resulted (see Army Field Manual 100-5, Operations). Chapter VII of this manual, Intelligence, is the mission statement of tactical intelligence support to the commander in the next decade. It defines and provides for the maximum integration and analysis of the factors of combat intelligence, i.e., enemy, weather, and terrain, which enable the commander to exploit his knowledge of the enemy relative to the advantages and limitations of weather and terrain. Tactical intelligence doctrine and training are undergoing intensive review and revision at the United States Army Intelligence Center and School (USAICS), Ft Huachuca, Arizona, to insure military intelligence (MI) personnel are fully equipped to meet the challenges of the future. One concept in this effort is called Intelligence Preparation of the Battlefield (IPB).

The key word in IPB is "preparation." Friendly forces are considered to be outnumbered and outgunned. Recent improvements in technology, intelligence concepts, and tactics "create a system more responsive to the tactical commander's needs than in any previous war." However, the commander and his forces, the intelligence system, and support units must be prepared to meet and suppress the threat on "day one." There will not be time to "gear up" as in the past. When the relative combat power factors are nearly equal, the use of terrain and weather hold the key to victory or defeat. When we acknowledge being outnumbered and outgunned, the importance of weather and terrain are significant factors of combat intelligence that must be fully considered before the next battle.

Weather data is an essential part of the Army's IPB. A primary function of USAICS is to focus attention on the commander's tactical weather requirements. A study called Tactical Environmental Support System (TESS) identified the major uses of, and types and sources of weather data. IPB uses the analytical technique of annotated maps, overlays, or templates to graphically integrate analyses

and evaluate the combined effects of weather and terrain on friendly and opposing forces. In addition, the information can be digitized, programmed into a computer, and displayed on a cathode ray tube (CRT). Thus IPB involves the detailed analysis of enemy, terrain, and weather prior to the battle.

Chapter 3*

OVERVIEW OF THE SUPPORT EFFORT

In June 1976, 7WS forwarded AWS and AFGWC a grid system covering both REFORGER exercise areas (V and VII Corps) with 12 x 17 mile resolution within the exercise area and 24 x 36 mile spacing outside the maneuver areas. A total of 114 grid points were identified to which climatic and forecast MSIs would be applied. Additionally, the elevation in meters of each grid point was determined. The grid points are given in Appendix B.

The scenarios mentioned in Chapter 1 were supported by providing the probability that weather conditions would be above: (1) 100 ft ceilings and 1/2 mile visibility, (2) 300 ft ceilings and 1 mile visibility, (3) 500 ft ceilings and 1 mile visibility, and (4) 1500 ft ceilings and 3 mile visibility. The six forecast times were 6, 12, 18, 24, 30, and 36 hours. MSIs were sent via AUTODIN and AWW to all 7WS field units and the deployed USAREUR Weather Support Unit (WSU). Figure 3-1 is a sample message. Figure 3-2 shows the MSI window.

AFGWC and USAFETAC tasked their programmers to design, code, test, and implement the scenarios decided upon. The team of scientists and programmers at AFGWC was led by Lt Col Billy Grubbs. He and his team spent 2500 manhours within a two month period to produce the forecasting algorithms and the computer software for the project. The team of scientists and programmers at USAFETAC was led by Mr. Murray Young. He and his team spent 4000 manhours within a four month period to produce the climatology algorithms for the 114 grid points. Capt (now Maj) Al Boehm, AWS Aerospace Sciences, provided invaluable assistance in the development of the algorithms and programs. Lt Col Coburn visited 2d Weather Wing (2WW) and 7th Weather Squadron (7WS) during the period 16-21 August 1976 to explain the MSI format, train both weathermen and customers in MSI support, and explain the benefits, limitations, use and tailoring of the products in the upcoming exercise. 7WS coordinated the final arrangements for MSI support including formatting, transmission, method of use, applicability, and post exercise analysis and verification. Maj Kyle, AWS Operations Evaluations Section, visited 2WW and 7WS units with Lt Col Coburn from 2-17 September 1976 during the exercise to obtain first-hand experience on the problems and successes of REFORGER 76.

*This chapter incorporates material from References 2 and 7.

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DE KAMM 011726Z SEP 76
ZUI KBLV UNKDTG
SXXL 40 KCWC

REFORGER SUCCESS INDICATORS BASED 1200Z 01 SEP 76
DIGITS ARE HIGH LIMIT IN TENS OF PERCENT / FOR EXAMPLE
1 IS 0 TO 10. ... 5 IS 41 TO 50. ... 9 IS 91 TO 100
06 HR FCST MSI
SCENARIO 1          SCENARIO 2          SCENARIO 3          SCENARIO 4
C 67 V 90           C 95 V 94           C 54 V 92           C 12 V 73
416346              758578              112112              111111
4634534             8867867             2312411             1111111
3532526             7887868             1421312             1111111
65355778            99888999            54243768            1111111
56674376777         9999889999          56674376788         1111111111
7355767777788       9899999999999999   72458587789HHH      1111111111222
167575656788888     8999999999999999   1782646469HHHHH     1111111111134
46667888888          9999999999999999   35679HHHHHH          1111111212
776756677777888     9999999999999999   466856787999HHH     1111111111112
7567668888888       9999999999999999   635867HHHHHH         111111111113
76677788             99999999            535789HH             11111113

12 HR FCST MSI
SCENARIO 1          SCENARIO 2          SCENARIO 3          SCENARIO 4
C 82 V 97           C 90 V 99           C 56 V 98           C 06 V 87
647567              889889              437367              111111
6766756             898888              6847856             1111111
6765757             8988889             6864747             1111111
77677778            99999999            9868799H            1111111
67776677778         9999999999999999   999986999HH9        11111111111
8677777777788       9999999999999999   H688H899999HHH      1111111111111
478777767778888     8999999999999999   4HH7989779HHHHH      1111111111112
6777777888          9999999999999999   6HH89HHHHHH          11111111111
7777677777778       9999999999999999   999HH898998HH9H     1111111111111
767777378778        9999999999999999   967977HHHHHH         11111111111
7777778             99999999            86788HH9H            1111111

18 HR FCST MSI
SCENARIO 1          SCENARIO 2          SCENARIO 3          SCENARIO 4
C 99 V 99           C 99 V 99           C 99 V 99           C 99 V 93
778778              999999              979799              112112
7877877             9999999             HH9HH99              222111
7877878             9999999             HH9HH9H              111211
HH788888            99999999             HH9HHHH              2222133
7888778888          9999999999999999   HHHHHHHHHHH          1111112212
8788888888888       9999999999999999   HHHHHHHHHHHHHHHHH   21134232212322
788888888888888     9999999999999999   9HHHHHHHHHHHHHHHH   122142211122133

```

FIGURE 3-1 - REFORGER BULLETIN

Probability of exceeding the criteria specified for each of the four scenarios at each of grid points given below.

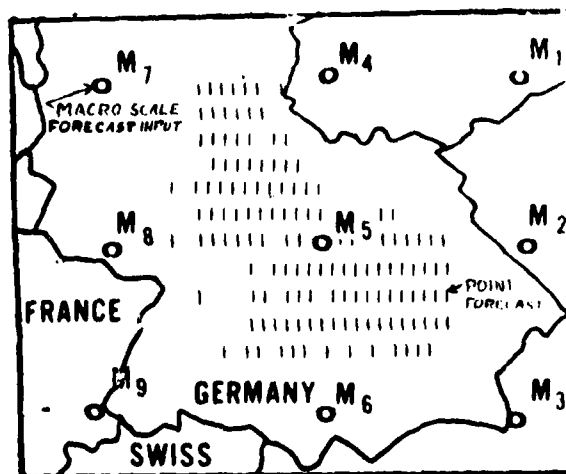


FIGURE 3-2 - REFORGER 76 MSI WINDOW

Chapter 4*

THE MODEL

4.1. Introduction

The model chosen to produce objective probability forecasts was the Transnormalized Regression Probability (TRP) Model. This model is a method that makes explicit use of climatological probabilities and requires a relatively small data base (Boehm, 1976). Table 4-1 contains the equation upon which the TRP model is based.

The implementation of the model consists of three procedures: transnormalization, correlation, and regression probability. For the REFORGER exercise, the equations developed in the regression procedure were used to make probability weather forecasts which were then blended with the Army supplied operational criteria probabilities to produce the MSIs. In addition to outlining AFGWC's steps in implementing the TRP model, this chapter contains a brief discussion of problem areas, corrected errors, and recommendations.

4.2. Model Development

4.2.1. Archival (Step 1). The first step was the archival of a developmental data set. Forecast fields were archived at AFGWC for the Boundary Layer Model (BLM), the Terminal Forecast Model (TFM) and the Objective Horizontal Weather Depiction Model (OHM). The forecast fields as well as the corresponding observations were archived at nine stations (Table 4-2) within the immediate vicinity of the 114 grid points of the exercise area. These nine stations were chosen because of their relative proximity to AFGWC half mesh grid points. This dependent sample covered the period 1200Z 1 July through 1200Z 6 August 1976. In addition, personnel at AWS Aerospace Services had been saving trajectory bulletins for three of the nine stations mentioned for most of 1976. Trajectory data for the spring (Mar-May) were used to develop the forecast equations. The fields and projections saved are shown in Table 4-3.

$$P = \frac{Y - \bar{M}}{\sqrt{1 - R^2}}$$

Y - CLIMATOLOGICAL PROBABILITY OF OBSERVATIONS \leq SPECIFIED PREDICTAND VALUE

\bar{Y} - Y IN TERMS OF END

P - PROBABILITY OF OBSERVATION \leq SPECIFIED PREDICTAND VALUE

\bar{P} - P IN TERMS OF END

$$\bar{M} = A_1 \bar{X}_1 + A_2 \bar{X}_2 + A_3 \bar{X}_3 + \dots + A_n \bar{X}_n$$

\bar{X}_i - PREDICTOR (IN TERMS OF END)

A_i - REGRESSION COEFFICIENTS

R - MULTIPLE CORRELATION COEFFICIENT OF \bar{M}

END - EQUIVALENT NORMAL DEViate

Table 4-1. The equation upon which the Transnormalized Regression Probability Model is based.

4.2.2. Transnormalization for Development (Step 2).

a. Transnormalization is a process whereby raw data fields are transformed into values of standard normal variables that have the same cumulative probability distribution as the raw predictors. The dependent data were transnormalized using the rank order method. The rank order

*This chapter incorporates Reference 3.

method consists of sorting the dependent data for a single field from lowest to highest value. If T is the total number of cases, the lowest value would have a cumulative probability of $1/T+1$, the second $2/T+1$, etc. (Panofsky and Brier, 1965, p. 43). The cumulative distribution was then put into terms of deviations from the standard normal distribution (END).

b. Because of the extremely small data sample, the decision was made to combine the 00Z and 12Z cycle times. It was felt that this mixing of data would not have a significant detrimental effect because the model operates in terms of END (i.e., the numerical value of a predictor is determined by its deviation from normal for that particular forecast hour and not strictly by its magnitude). Such an assumption would be invalid, assuredly, if the raw forecast fields were to be correlated directly to the observations.

4.2.3. Correlation (Step 3). The next step in the development was to find the simple correlation between each pair of transnormalized variables including all the predictors and the predictand. Because all the transnormalized forecast fields were used as continuous predictors, the common Product Moment Formula (Pearson, 1896) was used when any two forecast fields were correlated. The predictand was tested both as a continuous variable and as a dichotomous variable. When a dichotomous predictand field was correlated with a continuous forecast field, the formula for biserial correlation was used (Pearson, 1909).

<u>STATION</u>	<u>BLOCK STATION NUMBER</u>
Gera Leumnitz	09567
Grafenwöhr	10687
Salzburg/Flughafen	11150
Leinefelde	09449
Kitzingen	10659
Memmingen	10947
Köln/Bonn	10513
Ramstein	10614
Colmar/Meyenheim	07197

Table 4-2. Stations at which forecast fields and observations were archived.

4.2.4. Regression Coefficients I (Step 4).

a. As part of the implementation task, there was a requirement to find the regression equations ("M" of Table 4-1) that related the ENDS of the predictors to the ENDS of the predictands. Equations were needed that were valid over the entire grid, for both ceiling and visibility, and for projections of 6, 12, 18, 24, 30, and 36 hours.

b. The process began by offering all the 12 hour forecast fields from the BLM as possible predictors of 12 hour ceiling to a screening regression program. A separate correlation matrix was derived for each of the nine stations. These nine correlation matrices were then averaged using Fisher's Z-transformation (Table 4-4) (Fisher, 1914), resulting in a final combined correlation matrix. This correlation matrix was then inverted to find the coefficients of a generalized regression equation that could be used for all nine stations. The 24-hour forecast fields from the BLM were offered similarly to the screening program as possible predictors of 24-hour ceiling. A final "best" set of predictors was then chosen from these two sets and used to develop regression equations. The 12-hour projections of the final set of predictors were used in deriving a 12-hour regression equation for ceiling and the 24-hour projections were used in deriving a 24-hour regression equation for ceiling. Similar procedures were used to derive the visibility equations. The reason the same predictors (different projections) were used for both the 12- and 24-hour ceiling forecasts was to facilitate the derivation of the coefficients for the hours 6, 18, 30, and 36. This was done using an averaging technique that assumes a Markov process for the multiple correlation coefficients. (See Table 4-5).

c. This process was used with each of the models and resulted in separate ceiling equation and separate visibility equation with the associated multiple correlation coefficients for each of the models (BLM, TFM, OHM) and for each of the six projections. A similar procedure was used with the trajectory model for projects of 06, 12, 18, and 24 hours. Personnel at AWS had used three months of spring 1976 trajectory forecasts and the TRP model to derive equations for 36-hour projects of ceiling and visibility. These equations were used directly for the 36-hour trajectory forecasts. The 30-hour coefficients were found in the following manner:

$$R_{30} = (R_{36})^{30/36}$$

$$A_{i30} = \frac{R_{30}}{R_{36}} * A_{i36}$$

where R_n = multiple correlation coefficient for projection n.

A_{in} = regression coefficients for n hour projection, predictor i.

PREDICTOR FIELDS (From 00Z and 12Z cycles)

CONDITIONAL CLIMATOLOGY (Based on McCabe's modelled CC method)

CIG
VIS

BOUNDARY LAYER MODEL (12, 24 hr projections)

LEVELS

TT TEMPERATURE
RH RELATIVE HUMIDITY
SH SPECIFIC HUMIDITY
U U-WIND COMPONENT
V V-WIND COMPONENT

SFC, 150M, 300M, 600M
"
"
"
"

TRAJECTORY MODEL (12, 24, 36 hr projections)

TT TEMPERATURE
DP DEP POINT
LT LATITUDE (PARCEL BEGAN)
LG LONGITUDE (" ")
P PRESSURE (" ")
C CLOUD AMOUNT

GRADIENT, 850MB, 700MB, 500MB
"
850MB, 700MB, 500MB
"
"
"

TFM MODEL (12, 24 hr projections)

CIG CEILING
VIS VISIBILITY

SFC
"

OHM MODEL (12, 24 hr projections)

CIG CEILING
VIS VISIBILITY

SFC
"

PREDICTAND

TIMES

CEILING
VISIBILITY

12 HR INTERVALS
"

Table 4-3. Predictor and Predictand fields that were archived.

d. Equations for the Markov - Climatology - Observation model (MCO) were determined by simply using McCabe's (1968) results. Because the variables were in terms of equivalent normal deviates, the correlation between the ceiling now and the ceiling 12 hours later became the regression coefficient in the 12-hour one-term ceiling forecast equation. This was done for all six projections of both ceiling and visibility.

4.2.5. Regression Coefficients II (Step 5).

FISHER Z-TRANSFORMATION

$$w_{ij} = \text{TANH} \left(\frac{\sum_{k=1}^9 \text{ATANH}(w_{ijk})}{9} \right)$$

k = STATION

i = ROW OF PREDICTOR OR PREDICTAND

j = COLUMN OF PREDICTOR OR PREDICTAND

w_{ij} = ELEMENT OF CORRELATION MATRIX AT A STATION

w_{ij} = ELEMENT OF COMBINED CORRELATION MATRIX

Table 4-4. Fisher Z-Transformation used to average the correlation matrices for the dependent set in order to obtain a combined correlation matrix.

$$R_1 = (R_{24})^{1/24}$$

$$R'_1 = (R_{12})^{1/12}$$

$$R_6 = (R_{12})^{6/12}$$

$$R_{18} = \frac{(R'_1)^{18} + (R_1)^{18}}{2}$$

$$R_{30} = (R_1)^{30}$$

$$R_{36} = (R_1)^{36}$$

$$A_{i6} = \frac{R_6}{R_{12}} A_{i12}$$

$$A_{i18} = \left(\frac{R_{18}}{R_{24}} A_{i24} + \frac{R_{18}}{R_{12}} A_{i12} \right)$$

$$A_{i30} = A_{i24}$$

$$A_{i36} = A_{i24}$$

R_{24} = MULTIPLE CORRELATION (24 hr Predictors - 24 hr Predictand)

R_{12} = MULTIPLE CORRELATION (12 hr Predictors - 12 hr Predictand)

A_{in} = REGRESSION COEFFICIENTS FOR n HOUR PROJECTION, PREDICTOR i

Table 4-5. Averaging technique used to find the regression coefficients for 6, 18, 30 and 36 hour projections. Technique assumes a Markov process for the multiple correlation coefficients.

a. The next step was the derivation of a set of equations that combined the effects of all models. The 12- and 24-hour equations derived from each forecast model and the Markov - Climatology - Observation equations were used to make separate forecasts of ceiling and visibility. These forecasts of ceiling (visibility) in terms of END were then correlated with the observed ceiling (visibility) in order to obtain a final regression equation. These final regression equations for 12- and 24-hour projections were used to derive the 6-hour and 18-hour equations (Table 4-5). It was found that improvement in the correlation by including the TFM and OHM models was insignificant. Therefore, final regression equations were derived that blended the BLM, the Trajectory, and Markov - Climatology - Observation (MCO) model data. For the 30- and 36-hour forecast equations, a blend of the Trajectory and MCO model data was used. This final set of blended equations for six projections of ceiling and six projections of visibility was used in the operational program. (See Table 4-6). The equation sets for the individual models were used to make forecasts for comparison and verification purposes only.

CEILING

Predictors

		<u>BLM</u>	<u>TRAJ</u>	<u>MCO</u>	<u>MULTIPLE CORRELATION COEFFICIENT</u>
Projection	6 Hr	.449	.594	-.363	.834
	12 Hr	.374	.488	-.302	.695
	18 Hr	.266	.448	-.109	.615
	24 Hr	.184	.432	.046	.564
	30 Hr		.594	.083	.464
	36 Hr		.509	.071	.398

VISIBILITY

Predictors

Projection	6 Hr	.214	.524	.264	.796
	12 Hr	.171	.417	.210	.634
	18 Hr	.199	.406	.116	.584
	24 Hr	.240	.421	.037	.577
	30 Hr		.595	.087	.458
	36 Hr		.509	.075	.392

Table 4-6. Regression and correlation coefficients for blended equations. The predictors are the individual forecasts valid at the appropriate projection by the specific models.

b. Of some interest are the intercorrelations between the models. These were obtained as a by-product in this step. The correlations over the different projections and predictands varied considerably as the predictors changed with model and time. See Table 4-7.

12 Hr Projection (Cig)						24 Hr Projection (Cig)					
	TFM	OHM	BLM	TRAJ	MCO		TFM	OHM	BLM	TRAJ	MCO
TFM	1.000	.447	.544	.259	.220	TFM	1.000	.366	.466	.390	.294
OHM		1.000	.504	.372	.302	OHM		1.000	.379	.337	.409
BLM			1.000	.588	.333	BLM			1.000	.470	.297
TRAJ				1.000	.388	TRAJ				1.000	.384
MCO					1.000	MCO					1.000

12 Hr Projection (Vis)						24 Hr Projection (Vis)					
	TFM	OHM	BLM	TRAJ	MCO		TFM	OHM	BLM	TRAJ	MCO
TFM	1.000	.326	.250	.038	.191	TFM	1.000	.249	.421	.199	.246
OHM		1.000	.353	.027	.139	OHM		1.000	.415	.204	.142
BLM			1.000	.465	.306	BLM			1.000	.413	.267
TRAJ				1.000	.378	TRAJ				1.000	.297
MCO					1.000	MCO					1.000

Table 4-7. Intercorrelations between models for the 12 hour and 24 hour projections of ceiling and visibility.

4.2.6. END Functions (Step 6).

a. The operational program required that the forecast fields used as predictors be in terms of END. Because it was not feasible to use the rank order method of determining END in the operational mode, an alternate method was used. The observed cumulative frequency of the raw predictors was approximated by a mathematical function representing a simple curve. The functions used in this fitting process appear in Table 4-8.

1st order polynomial (Dixon 1973)

$$E = a_0 + a_1 x$$

2nd order polynomial

$$E = a_0 + a_1 x + a_2 x^2$$

3rd order polynomial

$$E = a_0 + a_1 x + a_2 x^2 + a_3 x^3$$

Johnson's Bounded (Johnson, 1949)

$$E = a_0 + a_1 \ln \left(\frac{x-a_1}{a_3-x} \right)$$

Johnson's Log - Normal

$$E = a_0 + a_1 \ln (x-a_2)$$

Johnson's Unbound

$$E = a_0 + a_1 \sinh (a_2 x + a_3)$$

Cornish Fisher (1937)

$$E = a_0 + a_1 y + a_2 y^2 + a_3 y^3$$

$$\text{where } y = \frac{x-a_4}{a_5} *$$

Gram - Charlier ** (ORD 1972)

$$P(E) = \frac{1}{\sqrt{2\pi}} e^{-x^2/2} (a_0 + a_1 y + a_2 y^2 + a_3 y^3)$$

$$+ \int_{-\infty}^y \frac{1}{\sqrt{2\pi}} \left(-\frac{x^2}{2} \right) dx$$

$$\text{where } y = \frac{x-a_4}{a_5}$$

* a_4 is mean and a_5 is standard deviation of x .

** Gram - Charlier $P(E)$ is in terms of cumulative probability and must be transformed into END.

Table 4-8. The observed cumulative frequencies of the raw predictors were approximated by the above mathematical functions. These functions were then used to convert the raw predictor values directly to Equivalent Normal Deviates.

b. Because of the limited data and the highly compressed timelines imposed, the forecast fields for each predictor of the BLM were lumped together to derive a single END function for that predictor (i.e., BLM surface relative humidity had one transformation function no matter what the projection, the station, or the time of day). For the Trajectory Model, three months of data at one station for one projection were used to derive END functions to be used no matter what the station, the projection, or the time of day. The third order polynomial (cubic) function consistently offered the best fit and was the END form chosen for all transformations.

4.2.7. Operational Program (Step 7). The final step in the process was to make forecasts on a real-time basis. The operational program to produce the forecasts consisted of the following nine main parts:

a. Retrieval from the AFGWC data base of all the necessary predictors from each model for all six projections.

b. Transformation of the predictors into END form using a separate cubic equation for each predictor.

c. Solution of the regression equations for each model. Each process in this step and in each of the following steps applied to each of six projections, for each of nine points, and for both ceiling and visibility.

d. Computation of the blended regression equations that combined the separate model components.

e. Interpolation of these values to the 114 point exercise grid.

f. Application of the climatological model (supplied by ETAC) to each of the 114 points.

g. The results from steps 5 and 6 were used to compute the TRP equation (Table 4-1), for each of the 114 grid points.

h. The final process in making the forecasts was the blending of the Army success probability threshold data (also furnished by USAFETAC) with the values computed in step 7. The final output was approximately 5500 forecasts per cycle.

i. The last step in the process was the dissemination of these forecasts to the field.

4.3. Problems Detected and Not Corrected

a. Unquestionably, the main problem was the extremely short suspense date. This severe handicap led to most of the following problems. The project was tasked on 28 June 1976 with production scheduled for 1 September 1976. This allowed no time for experimentation to determine the best methods or to perform badly needed quality control. Often the best method, even though known, was not used because of the time restriction.

b. END transformation functions for the BLM were derived by combining one month's data from nine stations for all projections. No allowance was made for diurnal effects, latitude/longitude, or projection. The END functions for TFM, OHM and MCO were developed by using the modeled climatology supplied by USAFETAC which contains several years of data. Trajectory END functions were derived from three month's data at a single station for one projection and used at all the projections. This had a negative influence on the verification as indicated by the fact that the TFM, OHM and MCO forecasts proved to be as good as or better than forecasts from the BLM, TRAJ, and the Blended models. Dependent data tests indicated that the TFM, OHM, and MCO had relatively low correlations with ceiling and visibility when compared with the BLM and TRAJ. The apparent reason why TFM, OHM, and MCO did as well as they did is that their equations consisted of only one or two terms while the BLM, TRAJ, and Blended had 10-25 terms; thus the equations for TFM, OHM, and MCO made use of only one or two fairly reliable END functions while BLM, TRAJ and, consequently, the Blended model made use of many potentially unreliable END functions.

c. Somewhat related to the first problem was the matter of too little data and the statistical instability associated with it. The END functions as well as the regression equations were derived from an unrealistically small data sample. As an example from the dependent sample, a BLM forecast surface wind u-component (west-east) between -3 and 0 knots would be within +2 standard deviations of the mean. However, when the exercise started, the synoptic weather conditions were slightly different from the small dependent data sample and a small positive u-component would give an END value of 6 or 7. That gave this predictor an unrealistic weight in the equation.

4.4. Problems Detected and Corrected

a. When the operational program was first implemented, the trajectory END transformation functions, although derived from only one station's data at the 36-hour projection, were all used "as is" at all the points. After several days, adjustments were made for the initial latitude/longitude and pressure of the parcel. This was necessary because the initial latitude/longitude depends on the location of the station and the initial pressure of the parcel depends on the projection.

b. Again, as a result of not having test time to "debug" the system, it was several days into production before the discovery was made that single precision coefficients for the END functions were not accurate enough to give a valid END. The ENDS from the third order polynomials were basically small differences between large numbers. To correct the problem, all coefficients were redefined in double precision form.

c. The hundreds of coefficients needed in the operational program were placed in data statements. This led to numerous keypunch errors. These were corrected as detected. Ideally, the development programs would punch or write these coefficients out to a file or tape to minimize the opportunity for human error.

d. Regression equations as well as END functions were derived using a July and early August data sample for the BLM and a Mar-May data sample for Trajectories for use during September. This also led to problems of the type indicated in paragraph 3. An attempt was made to account for this discrepancy by adjusting the coefficients of the END cubic functions. The following procedure supplied by AWS/DNT was the adjustment method attempted:

$$A' = A + B * X + C * X^2 + D * X^3$$

$$B' = B * Y + 2 * C * X * Y + 3 * D * X^2 * Y$$

$$C' = C * Y^2 + 3 * D * X * Y^2$$

$$D' = D * Y^3$$

$$X = (S - \bar{J})/V$$

$$Y = W/V$$

where:

A, B, C, D - original coefficients

A', B', C', D' - adjusted coefficients

\bar{S} - September mean value of raw predictor

\bar{J} - July mean value of raw predictor

W - Standard deviation for September of raw predictor

V - Standard deviation for July of raw predictor

Unfortunately this adjustment proved to be unstable, and frequently resulted in totally unrealistic END values. As a consequence, the original coefficients were used. During post analysis, the adjustment terms were rederived and showed that the above equations are correct with the exception that $X = \bar{S} - \frac{V}{W} \bar{J}$ and $Y = \frac{V}{W}$.

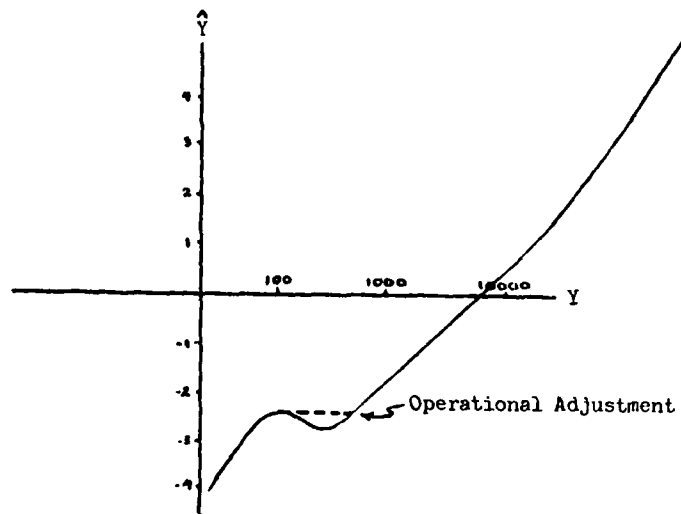
e. USAFETAC, also under a short time suspense, was unable to quality control the climatology model and, consequently, many points and/or stations had a poor climatological input. Frequently, the climatological cumulative frequency curves had a negative slope (i.e., a greater chance of ceilings less than 200 feet than less than 500 feet). The expedient solution chosen at AFGWC was to straight line the negative slopes. See Figure 4-1.

4.5. Recommended Improvements

a. The Markov-type approximation procedure which was used to develop the 06-, 18-, and 30-hour forecast equations appears to be inferior to what could have been developed by regression operations on a dependent data set for these time periods. This is inferred from verification results contained in Chapter 8. Again, lack of data and insufficient development time precluded testing to determine the best methods.

b. Offering only 12-hour forecast predictor fields for 12-hour forecasts, 24-hour forecast fields for 24-hour forecasts, etc., restricted the screening program in choosing the best predictors. This did not allow the statistical model to compensate for slowness or fastness of the forecast fields generated by the numerical models. Dependent sample tests showed, for instance, that the 24-hour forecast trajectory fields correlated better with the 12-hour ceiling than did the 12-hour forecast trajectory fields.

c. To generalize a particular equation, the correlation matrices at each of nine points were averaged using a Fisher Z-transformation technique. The averaged matrix was then inverted to determine the regression coefficients. Slightly better results were found with the dependent data when the nine points were combined, as if one station, and no direct averaging was done.



Y - Ceiling Height

"
Y - Cumulative climatological probability of Y in terms of END

Figure 4-1. An example of an operational adjustment made to a climatological curve.

d. Although the dependent data sample was too small to determine positively, it appears that better results could have been obtained if separate equations had been derived from each cycle. Further tests should be conducted on a much larger data set. If it is possible to use the same equation to start from any hour, tremendous advantage would accrue because of the additional flexibility gained and the decrease in the number of equations required.

e. Development of equations was performed with predictors and predictands transformed into their END value using the rank order method. In the operational mode, the predictors were transformed using the appropriate cubic function. It appears reasonable that better results might occur if the dependent data were transformed using the same functions that are to be used in the operational program.

f. Additional "after the fact" tests using the limited amount of dependent data available indicate that significantly better multiple correlation coefficients result when a combination of dichotomous and continuous predictor fields are used.

4.6. Conclusions. The short suspense date and the inadequate amount of dependent data resulted in an unfair test of the TRP model. Despite these problems, the TRP forecasts scored better at 18 hours, and were comparable at 24 hours to the 2WW subjective forecasts (see Chapter 8). The model has shown better results when tested under more optimal conditions (Boehm, 1976). The model may not have performed as well as expected because of steps taken in the name of expediency and not because of inherent flaws in the model. This can be proven only with more extensive testing with a greater amount of data.

Chapter 5*

CLIMATOLOGICAL MODEL

5.1. Introduction

Step six for producing an operational forecast on a real time basis was application of the climatological model (see 4.2.7(6)). USAFETAC developed the program "CLIMO" to produce the climatology for REFORGER 76. CLIMO produces the equivalent normal deviates (END) of four meteorological parameters. These parameters are ceiling, visibility, surface wind speed, and wind speed at 1500 feet above ground level (AGL) at 114 specified grid points in West Germany. The ENDs are converted to probabilities by the TAILOR program and mixed with criteria for success (both forecast and operator) and other operational probabilities to produce a decisionmaking display.

5.2. Data Base. The data base used to develop the CLIMO program was hand extracted and keypunched on computer cards from climatological summaries and terrain maps on file at USAFETAC. The basic development data consisted of cumulative distributions of ceiling and visibility for selected stations in the area of interest (within or close to the grid point area), surface wind speed frequency distributions from selected stations, and 3,000 feet mean sea level (MSL) wind summary for Munich, Germany for an approximation of the 1,500-foot AGL distribution of wind speed in the area of interest. Elements of terrain data for the selected stations as well as for the 114 grid points were compiled by hand. These elements consisted of:

- a. Latitude
- b. Longitude
- c. Elevation (in meters from mean sea level (MSL))
- d. The elevation of points 5 km north, south, east, and west of the station or grid point from which four slopes could be calculated.
- e. The distance to the nearest water (marsh, creek, river, lake, or ocean).

Table 5-1 lists the German stations used for modeling grid point climatology.

5.3. Computer Programs. The primary computer programs used in this study are a distribution fitting program (DISFIT) (5.3.1) and a stepwise multiple regression program (STEPR) (5.3.2).

5.3.1. DISFIT** is the program used to determine the equation that best describes the distribution of the meteorological parameter of interest. The climatological data is fit to eight different equations by DISFIT. These equations are:

- a. Cornish-Fisher
- b. 1st-order polynomial
- c. 2nd-order polynomial
- d. 3rd-order polynomial
- e. Johnson's SB $U = A + B \cdot \text{ALOG}((X-C)/(D-X))$
- f. Johnson's SU $U = A + B \cdot \text{ASINH}(C \cdot X + D)$
- g. Johnson's SL $U = A + B \cdot \text{ALOG}(X+C)$

¹The Defense Mapping and Aerospace Center (DMAAC) was tasked to use an automated extraction of the gridpoint terrain data. Development time precluded the use of their output for this study. It will be used in future studies.

*This chapter incorporates Reference 20.

**DISFIT is a program prepared by A. R. Boehm, AWS/DNT. Listings are available in USAFETAC/AD.

h. Gram-Chalier CUM.

$$\text{PROB} = Z(A + B*S + C*S**2 + D*S**3) + P*E$$

Results of the test studies on a sample of predictor stations indicated that the log of the meteorological element (e.g., the ceiling height) used in the 3rd-order polynomial equation best described the frequency distribution.

5.3.2. STEPR* is the multiple regression program that used each coefficient of the 3rd-order polynomial as a predictand to solve the regression equation using the elements of the terrain at the sample stations as the predictors (20 stations for ceiling and visibility; 7 for surface wind). The final equations to predict each of the coefficients of the 3rd-order polynomial distribution equation used 14 predictors; month, sine of the hour, cosine of the hour, (lat-50 deg)*(long+10 deg), (lat-50 deg)**2, (long+10 deg)**2, lat, long, elevation, north slope, south slope, east slope, west slope (the slopes were measured with the elevation of the station or grid point as the center point), and distance to nearest water.

Table 5-1. German Stations Used for Modeling Grid Point Climatology.

STATION	CEILING	VISIBILITY	SURFACE WIND
Sombach	X	X	
Finthen	X	X	
Mürth AAF	X	X	
Heidelberg	X	X	
Fulda	X	X	
Bahn AB	X	X	X
Ansbach AAF	X	X	
Frankfurt	X	X	
Kitzingen AAF	X	X	
Nürnberg	X	X	X
Stuttgart	X	X	X
Reuch AAF	X	X	
Hanau	X	X	
Wiesbaden	X	X	X
Niebelstadt AUX AF	X	X	
Lamstein	X	X	
Erding	X	X	
Zweibrücken	X	X	
Wasserkuppe	X	X	
Regensburg	X	X	
Würzburg			X
RAF			X
Maurice Rose AAF			X
Munich	for 1,500 ft wind model		

5.4. Example of CLIMO Application.

The CLIMO program is initiated by a call from the TAILOR program. The TAILOR program will have received a request to provide the probability of success display for a specified scenario (e.g., an operation involving a critical ceiling height value, a critical visibility value, a critical surface wind speed value, and/or a critical 1,500 ft AGL wind speed value) at a specified grid point. In order for the TAILOR program to do this, it calls CLIMO to produce the ENDS for each of the critical values. To do this, CLIMO uses the STEPR program to calculate the coefficients of the distribution equation (the predictands) using the elements of the terrain at the specified grid point (the predictors). The coefficients of the distribution equation (recall that the 3rd order polynomial was selected as the best distribution equation) are then used in the distribution equation with the critical value of the weather parameter (e.g., in the case of the ceiling height, the critical value might be 200 ft) as the X value in the equation to calculate the END of that

*STEPR is a program brought to USAFETAC from Pennsylvania State University and first adapted to the USAFETAC computer system by Capt Henderson. Listings are available in USAFETAC/AD.

weather parameter. TAILOR converts the ENDS of each critical value to probabilities and blends them with the statistics of the forecast and the other operational probabilities to produce a probability of success display.

A gross-error check of CLIMO indicates that the values appear to be in the correct magnitude with differences between actual and predictand probabilities ranging from 2% to 8%. The concept of predicting the climatology at a specific point has proved workable, the technique was developed further in REFORGER 77 support.

Chapter 6*

TEST OF "CLIMO"

6.1. Introduction

USAFETAC prepared a study to see how well the CLIMO Program reproduced climatology. This program can be tested by reproducing the cumulative probability distributions of selected weather parameters at a selected station. For this test, the program was set to reproduce the cumulative percentage frequencies of the ceiling and the visibility in the format of Section D of the Air Weather Service Revised Uniform Summary of Surface Weather Observations (RUSSWO). Three nearby stations with different elevations were used for the independent test.

6.2. Discussion

Ceiling, visibility, and wind data from 23 stations were used in the CLIMO dependent study. Of these 23 stations, only 20 stations were used for the ceiling and visibility. The additional three stations were used for the wind. These wind statistics failed to produce any realistic results. The additional three independent nearby stations were selected from the RUSSWOs to represent a range of heights and are indicated in Figure 6-1 by circles. The test stations are:

<u>WMO NO.</u>	<u>STATION</u>	<u>ELEVATION (above MSL)</u>
107295	Sandhofen, Germany	108 m (334 ft)
106870	Grafenwöhr, Germany	415 m (1360 ft)
109710	Bad Tölz, Germany	716 m (2360 ft)

In the independent study, the hours of 0700 and 1600 LST were tested for the months of September, October, and November.

6.3. Test Procedures

Assuming that the observed frequencies and the model frequencies were the same, a test was made using the Kolmogorov-Smirnov One-Sample Test described by Siegel (2).

Table 6-1 shows the results of one test for a specific month, time of day, and test station. This table is described in detail because it shows the format for all other months, hours, and parameters tested.

The ceiling summaries in Table 6-1 contain 31 categories of heights ranging downward from 20,000 feet to zero feet. The largest difference between categories of the observed and modeled is used in the Kolmogorov-Smirnov One-Sample Test. For example, the maximum difference is at the 12,000-ft category (16.7% or 0.1670). This difference is greater than the critical value, 0.0553; thus, the difference is considered significant. Figure 6-2 is a plot of the observed data and model output. Three more of these detailed breakdowns of the test are included in Table 6-2 and Figure 6-3, Table 6-3 and Figure 6-4, and Table 6-4 and Figure 6-5. To reduce the amount of table preparation, only the significance test portions and a limited amount of data for the remaining months, hours, and stations are shown. Tables 6-5 and 6-6 show ceilings and visibilities, respectively. The differences in the values for the observed data and the model output for Bad Tölz were so great that a significance test was not needed.

It should be noted that, although CLIMO was a crude first attempt to model climatology, the modeled ceiling's below 3000 feet closely approximated the observed ceilings. The observations of ceilings less than 3000 feet are questionable: Table 6-1 shows no observed ceilings between 700 and 1000 feet; Table 6-2 shows none between 500 and 1000 feet. There also appears to be observer bias in the regions where modeled and observed climatology differ the most, e.g., Table 6-1 indicates no ceilings observed between 14,000 and 20,000 feet.

6.4. Conclusions

Statistically, the observed and the modeled summaries were shown to be significantly different for all of the cases. However, the only requirement levied on the modeled climatology was an error less

*This chapter incorporates Reference 21.

than 10%. Furthermore, the Kolmogorov-Smirnov (KS) significance test may be inappropriate for several reasons: (1) the KS test is for continuously observed data, RUSSWO data has been categorized; (2) no account was made for serial correlation; and (3) the goal was to approximate the distribution, not get a "true" fit.

While the model seemed to work, it still needs further study. Possibly a different distribution equation (from DISFIT (20)) should be used. We need dependent sample data that includes, if available, more reliable observations as well as one that includes stations at higher elevations. In any event, further development studies are needed if this concept of prediction or spreading is to be used.

Table 6-1. Sandhofen, Germany: Observed- and Model-Produced Cumulative Summaries of Ceiling Heights (RUSSWO format) for September, 0700 LST.

CEILING HEIGHT (100's of feet)	FREQUENCIES (Cumulative Percent \geq Ceiling Height)	
	OBSERVED	MODEL
200	50.8	63.7
180	50.8	64.4
160	50.8	65.3
140	50.8	66.4
120	51.2	67.9
100	54.9	69.8
90	57.2	71.0
80	61.3	72.4
70	66.1	74.0
60	71.3	75.9
50	75.9	78.2
45	78.7	79.5
40	81.2	80.9
35	82.7	82.5
30	85.5	84.3
25	89.7	86.3
20	91.3	88.6
18	91.5	89.6
15	92.9	91.2
12	94.1	92.9
10	94.3	94.1
9	94.3	94.7
8	94.3	95.3
7	94.3	95.9
6	94.9	96.5
5	95.2	97.2
4	95.5	97.8
3	96.5	98.3
2	97.5	98.9
1	98.6	99.4
0	100.0	100.0

SIGNIFICANCE TEST: Critical value (.01) = 0.0553

Observed and model are significantly different

Table 6-2. Sandhofen, Germany: Ceiling Heights for September, 1600 LST.

CEILING HEIGHT (100's of feet)	FREQUENCIES (Cumulative Percent \geq Ceiling Height)	
	OBSERVED	MODEL
200	56.3	72.4
180	56.3	72.1
160	56.3	72.1
140	56.6	72.4
120	57.5	73.1
100	60.6	74.5
90	64.3	75.6
80	69.4	76.9
70	73.3	78.5
60	78.0	80.6
50	81.6	83.1
45	86.1	84.6
40	88.6	86.3
35	92.6	88.1
30	95.0	90.1
25	97.3	92.2
20	97.9	94.4
18	98.2	95.3
15	99.0	96.5
12	99.4	97.7
10	99.8	98.4
9	99.8	98.7
8	99.8	99.0
7	99.8	99.2
6	99.8	99.4
5	99.8	99.6
4	100.0	99.7
3	100.0	99.8
2	100.0	99.9
1	100.0	100.0
0	100.0	100.0

SIGNIFICANCE TEST: Critical value (.01) = 0.0536

Observed and model are significantly different

Table 6-3. Sandhofen, Germany: Observed- and Model-Produced Cumulative Summaries of Visibility (RUSSWO format) for September, 0700 LST.

VISIBILITY (Miles)	FREQUENCIES (Cumulative Percent \geq Visibility)	
	OBSERVED	MODEL
10	--	28.9
6	21.8	37.7
5	28.5	42.0
4	36.9	48.0
3	48.2	56.3
2½	51.8	61.8
2	62.0	68.4
1½	69.6	76.1
1¼	71.4	80.4
1	79.2	84.8
¾	82.0	89.4
5/8	83.1	91.5
1/2	84.5	93.6
5/16	87.1	96.2
1/4	87.5	96.8
0	100.0	100.0

SIGNIFICANCE TEST: Critical value (.01) = 0.0539

Observed and model are significantly different

Table 6-4. Sandhofen, Germany: Visibility for September, 1600 LST.

VISIBILITY (Miles)	FREQUENCIES (Cumulative Percent \geq Visibility)	
	OBSERVED	MODEL
10	--	61.6
6	73.1	66.2
5	81.2	69.8
4	89.6	75.0
3	94.0	82.2
2½	95.3	86.4
2	97.1	90.8
1½	98.5	95.0
1¼	98.7	96.7
1	98.8	98.1
¾	99.0	99.1
5/8	99.5	99.4
1/2	99.6	99.7
5/16	100.0	99.8
1/4	100.0	99.9
0	100.0	100.0

SIGNIFICANCE TEST: Critical value (.01) = 0.0536

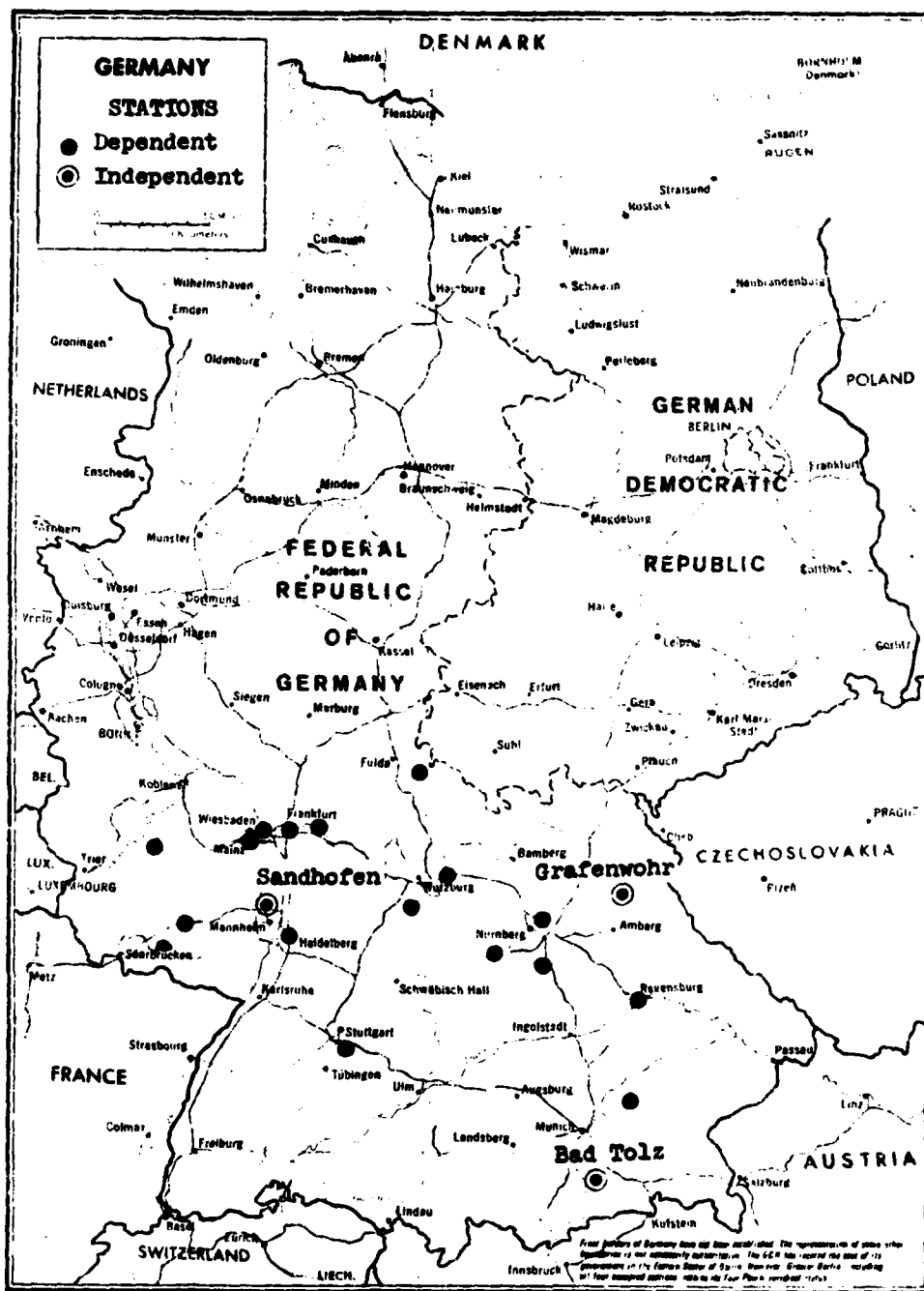
Observed and model are significantly different

Table 6-5. Significance Test - Ceiling.

STATION	MONTH	HOUR		CRITICAL VALUE	SIG DIF AT .01 LEVEL
		LST	MAX DIF		
Sandhofen (107295)	OCT	0700	0.2670	0.0526	Yes
		1600	0.2460	0.0525	Yes
Sandhofen (107295)	NOV	0700	0.3190	0.0545	Yes
		1600	0.4120	0.0539	Yes
Sandhofen (106870)	SEP	0700	0.1970	0.0513	Yes
		1600	0.2260	0.0515	Yes
Grafenwöhr (106870) Figs 6 & 7	OCT	0700	0.1000	0.0504	Yes
		1600	0.1860	0.0507	Yes
Grafenwöhr (106870)	NOV	0700	0.1380	0.0516	Yes
		1600	0.1290	0.0519	Yes

Table 6-6. Significance Test - Visibility.

STATION	MONTH	HOUR LST	MAX DIF	CRITICAL VALUE	SIG DIF AT .01 LEVEL
Sandhofen (107295)	OCT	0700	0.0850	0.0526	Yes
		1600	0.0650	0.0525	Yes
Sandhofen (107295)	NOV	0700	0.2980	0.0545	Yes
		1600	0.0700	0.0539	Yes
Grafenwöhr (106870)	SEP	0700	0.1480	0.0513	Yes
		1600	0.2930	0.0515	Yes
Grafenwöhr (106870) figs 8 & 9	OCT	0700	0.1280	0.0504	Yes
		1600	0.2820	0.0501	Yes
Grafenwöhr (106870)	NOV	0700	0.3060	0.0516	Yes
		1600	0.2100	0.0519	Yes



026.5 1:75

Figure 6-1. Stations Used in Study.

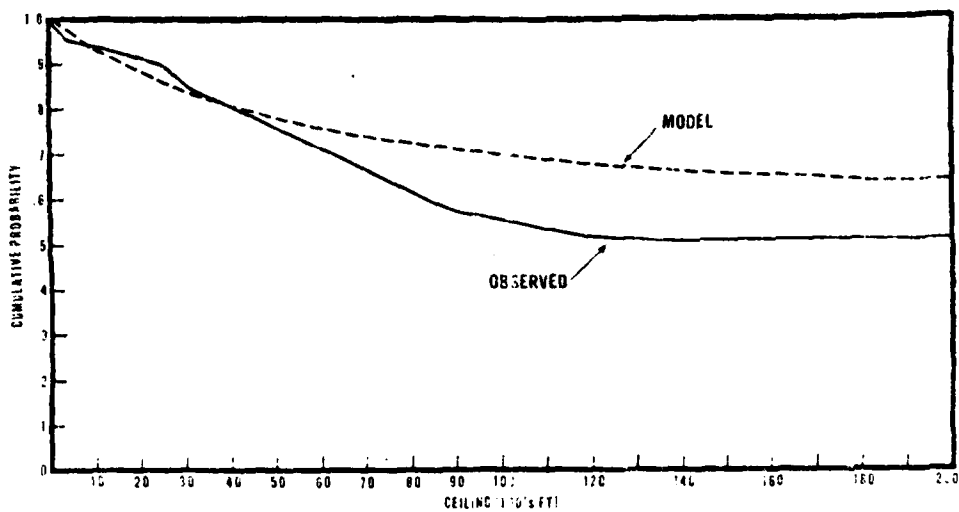


Figure 6-2. SANDHOFEN 0700L SEPTEMBER SIGNIFICANTLY DIFFERENT

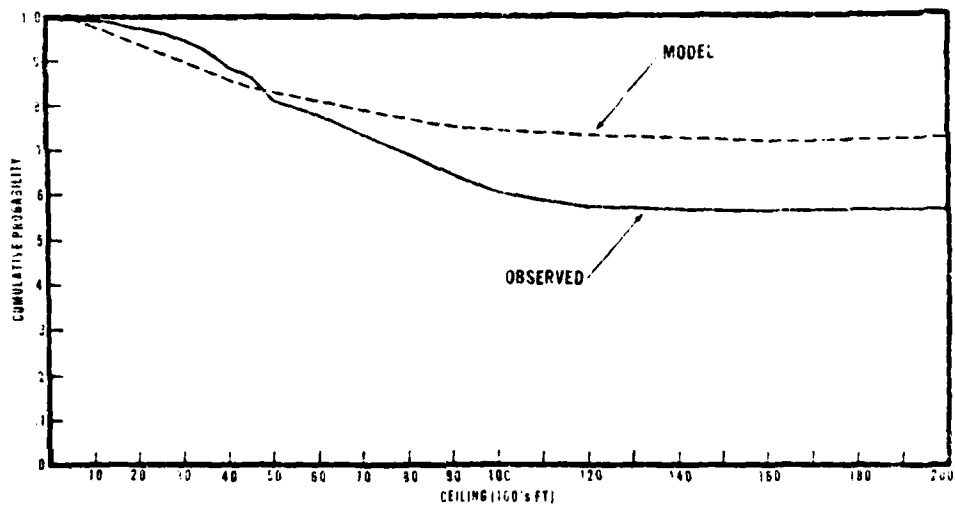


Figure 6-3. SANDHOFEN 1600L SEPTEMBER SIGNIFICANTLY DIFFERENT

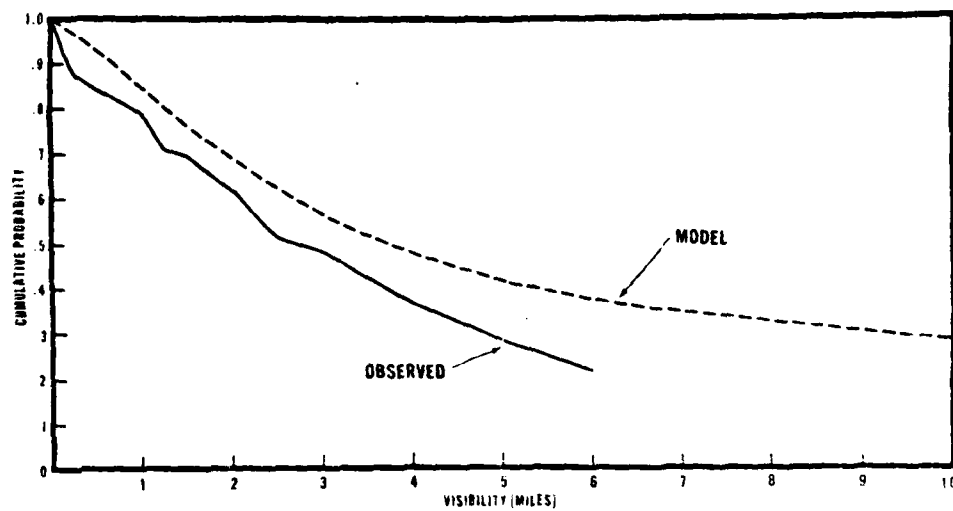


Figure 6-4. SANDHOFEN 0700L SEPTEMBER SIGNIFICANTLY DIFFERENT MODEL OBSERVED

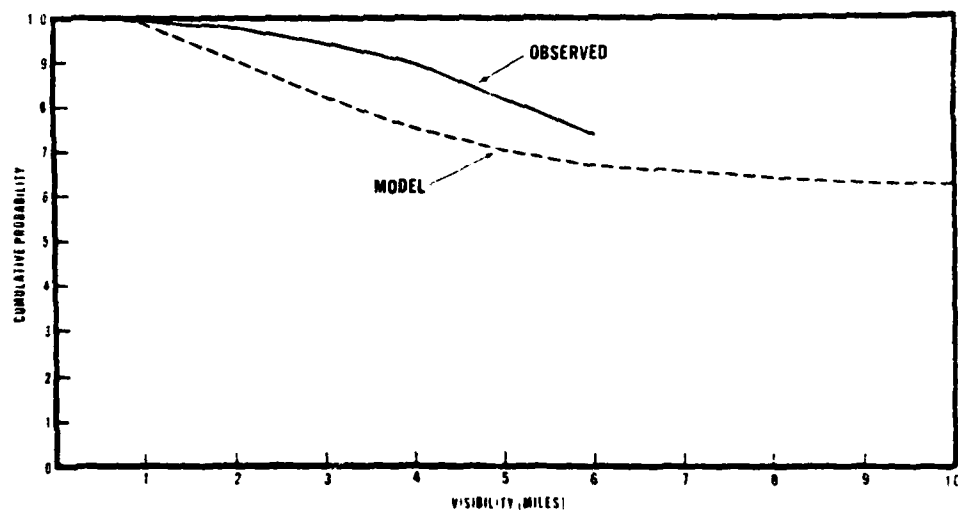


Figure 6-5. SANDHOFEN 1600L SEPTEMBER SIGNIFICANTLY DIFFERENT

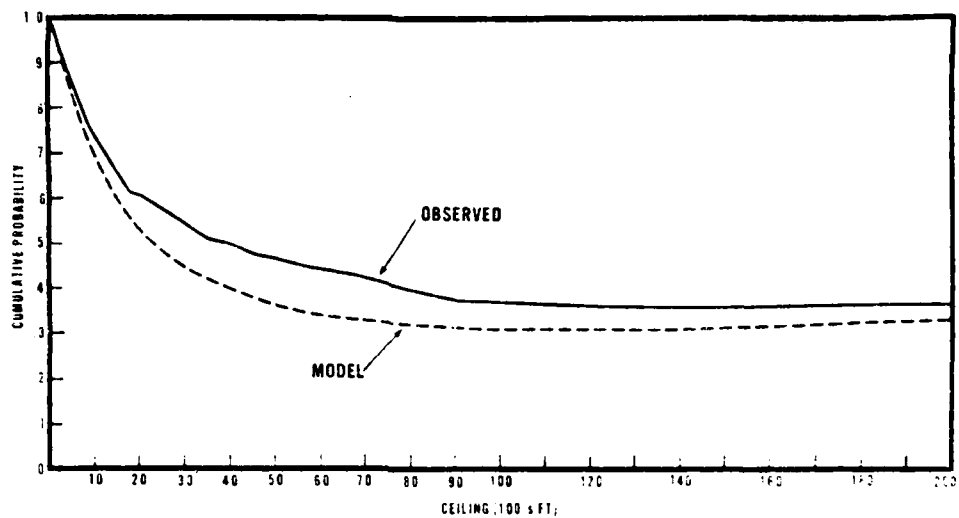


Figure 6-6. GRAFENWOHR 0700L OCTOBER SIGNIFICANTLY DIFFERENT

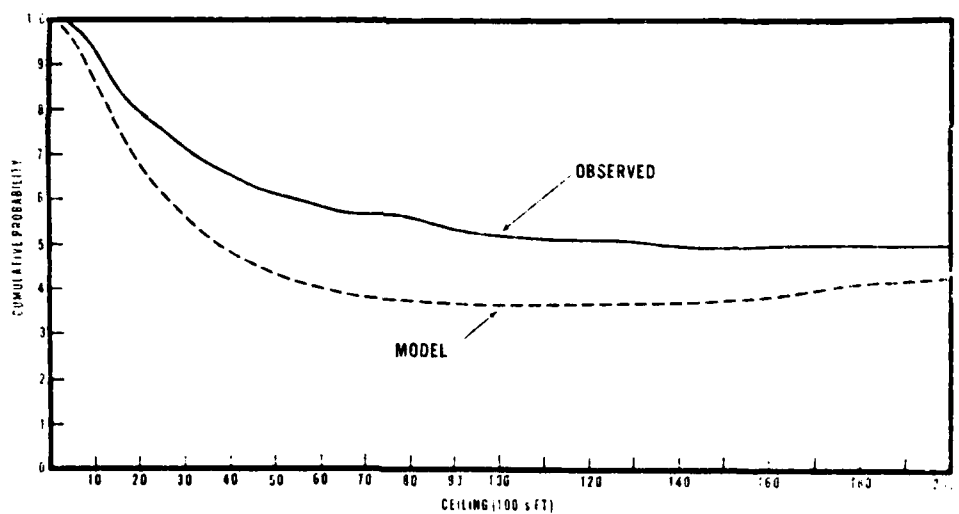


Figure 6-7. GRAFENWOHR 1600L OCTOBER SIGNIFICANTLY DIFFERENT

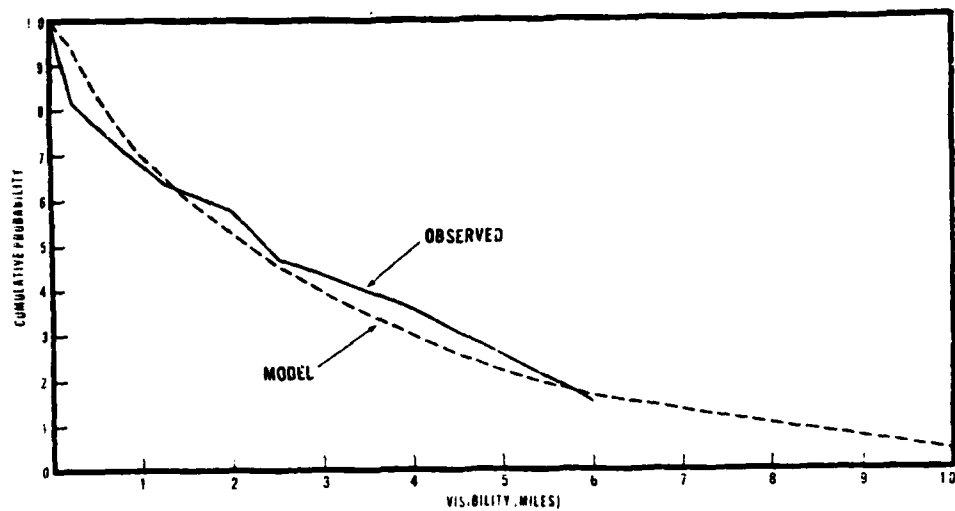


Figure 6-8. GRAFENWOHR 0700L OCTOBER SIGNIFICANTLY DIFFERENT

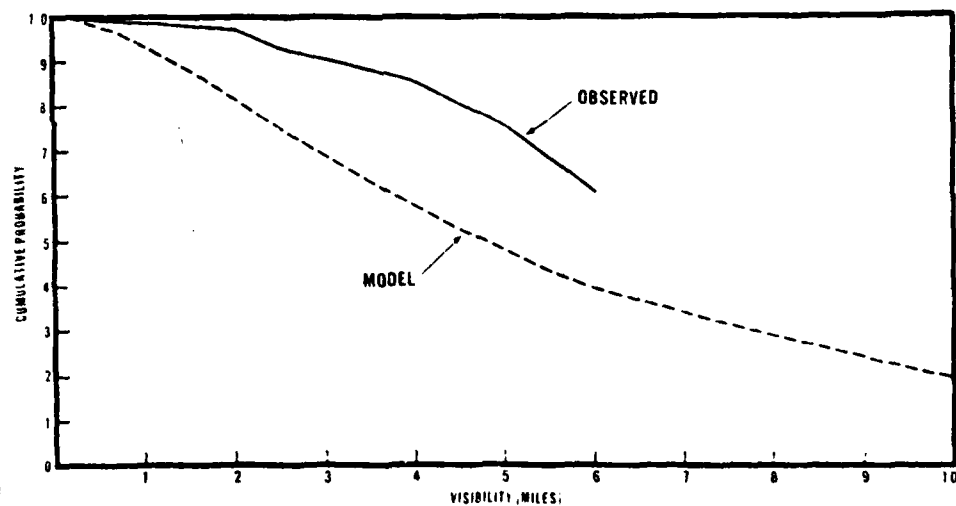


Figure 6-9. GRAFENWOHR 1600L OCTOBER SIGNIFICANTLY DIFFERENT

Chapter 7*

SIMULATED MISSION SUCCESS INDICATORS

7.1. Introduction

The USAFETAC support to REFORGER 76 consisted not only of establishing a climatological data base and developing the "CLIMO" program, but also developing the applications programs for producing Simulated Mission Success Indicators (SMSIs). SMSIs show the effect of weather on mission accomplishment, attrition, and resource requirement. They can also be used to determine the desirability of various force structures, tactics, and weapon systems, as well as to assess the weather limitations on enemy operations.

The development effort for SMSIs involved producing the Geo-Clim model for obtaining climatological probabilities of ceiling and visibilities, and building the program structure which incorporated the key components of TRP (Boehm, 1976) and MSI generation. The major portion of the programming effort was accomplished by USAFETAC/ADP (Programming Applications Section) within severe time constraints.

7.2. Theoretical Considerations:

a. The underlying theory for the generation of Simulated Mission Success Indicators is contained in the theory for the normal and bivariate normal probability distributions, normalization and equivalent normal deviates (END) of variables, and correlation coefficients which display a Markovian time decay.

b. A Mission Success Indicator is the probability that a mission will succeed. An MSI is tailored to a specific decision. An MSI includes those weather (probability forecasts) and nonweather parameters that are needed to make an optimal decision. SMSIs are decision tailored probability values which take into account the climatological probability of a weather event, the decay of forecast-observation correlation in time, and the weapon system characteristics.

c. The SMSI program calculated the MSI's using the equation

$$MSI = \sum_I \sum_J P(C(I) V(J)) * WTCV(I,J) \quad (7-1)$$

where P is the probability of the ceiling and/or visibility event and WTCV is the mission-weighting factor for the given ceiling-visibility conditions. The mission weighting factors are provided in Table 7-1. Note that the mission weighting factor, WTCV (I,J) in equation 7-1, is a constant for missions other than Close Air Support which uses a discrete distribution of values. For the case of a constant mission weighting factor, WTCV (I,J) can be taken out of the summations in equation 7-1.

d. The cumulative probability for ceiling or visibility was determined from multi-linear regression analysis relating climatology of a specified variable to geographical parameters. This has been named the "Geo-Clim" modeling approach. The cubic equation of the natural logarithm of the variable was determined to be the "best fit" and was of the form

$$END(x) = A + B \ln(x) + C \ln^2(x) + D \ln^3(x) \quad (7-2)$$

where END(x) was the equivalent normal deviate of the variable x and A, B, C, and D are fitted coefficients. Each of these coefficients were determined by correlation with 15 geophysical parameters of each location (grid point/I,J): latitude, longitude, elevation, four-direction slopes, distance to water, cosine and sine of the time of day, date; three other latitude-longitude factors; and a fitting constant thus, sixty numbers contain all input required to generate the complete ceiling and visibility climatology for any grid point.

*This chapter incorporates Reference 14.

Table 7-1. Mission weighting factors for ceiling and visibility.

Mission	WTCV*	Critical Cig (ft)	Critical Vsby (m)
Tow-1	.51	100	1000
Tow-2	.72	100	2000
Dragon 105-1	.85	0	1000
Dragon 105-2	.35	0	2000
VFR	1.0	300	1600
Paradrop	1.0	1500	4800

Close Air Support Visibility Category (10² meters)

		80	72	64	56	48	48	48	48	48	40	00
Ceiling	90	.47	0	0	0	0	0	0	0	0	0	0
Category	50	0	.31	0	0	0	0	0	0	0	0	0
	35	0	0	.24	0	0	0	0	0	0	0	0
(10 ² ft)	27.5	0	0	0	.23	0	0	0	0	0	0	0
	23.5	0	0	0	0	.22	-	-	-	-	0	0
	21.0	0	0	0	0	-	.21	-	-	-	0	0
	17.5	0	0	0	0	-	-	.17	-	-	0	0
	12.5	0	0	0	0	-	-	-	.08	-	0	0
	7.5	0	0	0	0	-	-	-	-	.04	0	0
	4.0	0	0	0	0	0	0	0	0	0	.02	0
	0.0	0	0	0	0	0	0	0	0	0	0	0

*One weighting factor assumed for all combinations of ceiling and visibility.

e. For mission criteria which are sensitive to both ceiling and visibility, a means of obtaining a joint probability was approximated using

$$P_{CV} = .7(P_C)(P_V) + .3 \text{ MIN } (P_C, P_V) \quad (7-3)$$

where P_{CV} is the joint probability, P_C is the probability the ceiling is greater than or equal to some value, P_V is the probability the visibility is greater than or equal to some threshold, and MIN defines selection of the smaller of the two probabilities, P_C or P_V . This allows great flexibility because an entire table of joint probabilities need not be stored but only the independent probabilities need be known.

f. The tables generated for SMSI's were accomplished through the TRP model using a linear combination of normally distributed variables based upon a modeled forecast distribution and a Markovian time dependent correlation coefficient. An equation of the form (Gringorten, 1972):

$$\hat{P} = \frac{\bar{Y} - RN}{\sqrt{1 - R^2}} \quad (7-4)$$

was used, where \hat{P} is the END determined by distribution of N , \bar{Y} is the climatological value (END) for the variable, N is normally distributed with unit variance, and R is the correlation coefficient. The Y value is set for a particular grid point and time from regression equations of the "Geo-Clim" model. The correlation coefficient, R , is set by the length of forecast, where the relationship to time is

$$R_t = R_0^t \quad (7-5)$$

where t is in hours. R_0 was assumed to be equal to 0.98.

g. A rational mathematical function is used from Abramowitz (1965) which converts from END to cumulative probability.

PNORM (X): normalized probability of x

(Eq: 26.2.18, Abramowitz; 1965)

$$P(n) = 1 - 1/2 (1 + C_1 n + C_2 n^2 + C_3 n^3 + C_4 n^4)^{-4} \quad (7-6)$$

$$C_1 = .196854 \quad C_3 = .000344$$

$$C_2 = .115194 \quad C_4 = .019527$$

h. A rational mathematical function is used (Abramowitz, 1965) to convert from cumulative probability to equivalent normal deviates.

XGPX(P): equivalent normal deviate of probability

(Eq: 26.2.23, Abramowitz, 1965)

$$t = \sqrt{\ln \frac{1}{p^2}}$$

$$x(p) = \frac{t - C_0 + C_1 t + C_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \quad (7-7)$$

$$C_0 = 2.515517 \quad d_1 = 1.432788$$

$$C_1 = 0.802853 \quad d_2 = 0.189269$$

$$C_2 = 0.010328 \quad d_3 = 0.001308$$

i. A mathematical function was used to integrate over the bivariate normal distribution given the unconditional probabilities of x and y as obtained from the TRP equation $x = (y - \Delta p)/D$ where y is the unconditional or joint probability of an event, p is threshold probability from .05 to .95 and D is $\sqrt{(1-R)^2}$. The equations used are detailed on pages 23 and 24 of reference 6 and were derived from equations 26.2.1, 26.2.3, 26.2.27, 26.3.1, 26.3.3, and 26.3.29 of Abramowitz (1965).

7.3. SMSI Program Concepts

a. The purpose of this applications program was to provide Simulated Mission Success Indicators for support to REFORGER 76 operations. The program was designed to simulate any of the seven missions and produce a critical probabilities table for the mission/month/time of day/forecast time desired. The output tables represent the values contained in a contingency table of the form

		MISSION FORECAST	
		GO	NO GO
MISSION SUCCEEDED	YES	A	B
	NO	C	D

where the following values represent:

A = Mission executed with success

B = Mission not executed due to predicted bad weather, would have succeeded (missed opportunity)

C = Mission executed, did not succeed

D = Mission not executed, would not have succeeded

b. The probability tables generated by the SMSI programs are shown by Tables 7-2 and 7-3. Values using the Table 7-2 format were generated using the mission weighting factor distribution for close air support. When the mission weighting factor is constant, WTCV (I,J) can be taken out of the summations in equation 7-1. In this case the format in Table 7-3 is used. A' is computed from the weather event portion of equation 7-1. A can then be computed by multiplying A' times the constant mission weighting factor to get A. Note that MSIs can only be as high as the constant mission weighting factor or the highest value when using non-constant values since these values could only result when the weather event probability is 100%. Thus the maximum P possible for Table 7-2 is 0.5 corresponding to the close air support success in perfect weather. Tables D-1 and D-2 show sample outputs of SMSIs using the formats of Tables 7-2 and 7-3 respectively.

Table 7-2. SMSI-Contingency Table Relationship

MISSION: Close Air Support

FORECAST TIME LENGTH = 12 Valid at 1200Z

MONTH = September

PRODUCED BY USAFETAC

<u>Grid Point</u>	<u>Critical Probability</u>	<u>Mission Exec With Success</u>	<u>Mission Not Exec Would Have Succeeded</u>	<u>Mission Exec Did Not Succeed</u>	<u>Mission Not Exec And Would Not Have Succeeded</u>
2	.050				
2	.100				
2	.150				
2	.200				
2	.250				
2	.300	A	B	C	C
2	.350				
2	.400				
2	.450				
2	.500				

Table 7-3. SMSI Printout - program "Scores"

MISSION: TOW-2

FORECAST TIME LENGTH = 12 Valid at 1200

MONTH = September

PRODUCED BY USAFETAC

<u>Grid Point</u>	<u>Critical Probability</u>	<u>Mission Exec Weather OK</u>	<u>Mission Exec With Success</u>	<u>Mission Not Exec Could Have Gone</u>	<u>Mission Exec Wx No Gone</u>	<u>Mission Not Exec And Would Not Have Succeeded</u>
1	.050					
1	.100					
1	.150	A'	A	B	C	D
1	.200					
1	.250					

c. The SMSI program structures are given in Appendix D. Flow charts and required input for these programs are shown. In addition, flow charts and calling parameters of functions used by the main programs are provided.

7.4. Conclusion and Recommendation

a. The technique provides the user a capability for an objective selection of critical probabilities on which to threshold a go/no go decision. The SMSI approach gives weighted (or unweighted) values with which an apriori evaluation can be made. Through an analysis of the A, B, C, and D values of the contingency table, a critical probability can be selected by an operator that best suits his mission requirements and limitations. The key factor in the SMSI production is the modeled forecast distribution which has a significant effect on the selected critical probability for a given valid time. The probability forecast distribution depends only on the event climatology and the skill (correlation) in predicting event occurrence. When the correlation coefficient R goes to zero, the result is that climatological MSIs (CMSIs) are obtained.

b. The following are recommendations for modification to the current SMSI program and the techniques employed.

(1) SMSI Program should be modified to contain a matrix containing all "ones" as weapon system effectiveness. This would allow production of SMSIs which were independent of weapon system and allow operator application of weighting parameters. This would allow gaming on his part in the selection of weapon system as well as armament trade-offs.

(2) Generation of END values from regression equations requires additional development. Currently, function CLIM can generate negative slopes and nonmonotonically increasing values of END. This can be corrected through testing and selection of different regression equations that do not generate negative slopes. When the actual climatological frequency for a given event, time, and location is known it should be used directly.

(3) A generalized means of generating point climatology is required for ceiling and visibility, as well as other important variables such as CFLOS, winds, clouds, soil moisture, and precipitable water. Since these factors affect mission efficiency as they impact on bombing accuracy, EO weapon performance, etc., the development of a means to produce a point climatology for these variables is imperative.

(4) Further study should be undertaken to verify the decay of correlation with time between observations and forecasts. The initial value may differ from 0.98 or it may be variable over specified time lengths, e.g., during 6-12 hrs it may be 0.96 and during 12-24 hrs 0.985. This relationship may also be dependent upon geographical location as well as the meteorological variable being forecast.

(5) Customer feedback should be an integral part of any use of SMSIs. Customer mission outcome should be verified to compare against the contingency table of A, B, C, and D for the selected threshold.

Chapter 8*

VERIFICATION

8.1. Introduction. Evaluation of the various forecasts produced during the exercise was provided by independent verification for six of the nine European weather stations. These stations were also used to produce the dependent data sample from which the system was developed. These six stations were:

<u>Call Letters</u>	<u>Name</u>
EDIC	Grafenwöhr
LOWS	Salzburg
EDIN	Kitzingen
EDDK	Köln/Bonn
EDAR	Ramstein
LFSC	Colmar/Meyenheim

8.2. Data. The data collection period for the verification was as follows:

- AWS category 4 and 5 data: 1 Sep - 5 Oct 76
- MSI data: 14 Sep - 5 Oct 76
- 2WW four-category subjective forecasts: 1-30 Sep 76

The data were categorized for verification as shown below:

- AWS Product Evaluation Program (PEP) categories:

<u>Ceiling (ft)</u>	<u>Category</u>	<u>Visibility (mi)</u>
< 200	1	< 1/4
200 - 999	2	1/4 < 2
1000 - 2999	3	2 < 3
3000 - 9999	4	3 < 6
> 10000	5	≥ 6

- AWS PEP combined categories (ceiling values in feet, visibility values in miles):

<u>Category</u>	<u>Criteria</u>
1	< 200/1/4
2	200/1/4 < 1000/2
3	1000/2 < 3000/3
4	≥ 3000/3

c. 2WW subjective joint probability data: These were identical to the AWS four category joint probability criteria except that 2WW also made a forecast for conditions less than 100/1/4. For compatibility with the AFGWC automated forecasts, this category's probabilities were included in the probabilities for the condition of less than 200/1/4. This resulted in four categories that could be directly compared to the automated forecasts.

- Exercise scenario criteria for MSI forecasts:

<u>Mission Nr/Type</u>	<u>Criteria</u>
1: Cobra - TOW Missile	< 100/1/4 (2 km)
2: 105mm Howitzer	< 10/5/8 mi (1 km)
3: Helicopter VFR	Day (12Z): < 100/1/4 Night (00,06,18Z): < 10/5/8 mi
4: Close Air Support	Complex combinations of ceiling and visibility values from 400/1/4 to 1000/2

*This chapter is Reference 4.

8.3. Use of Data in Models. Forecasts for the six locations were produced by six different models plus persistence. These models were described in previous chapters. The TRP blended model was the only one used to produce the operational MSI forecasts. The remaining models' forecasts were produced solely for the purpose of comparative verification. To obtain a sufficiently large sample size, the data from all six stations for each time period were consolidated into a single data set. The statistical results of the evaluation are contained in Tables 8-1 through 8-5 and Figures 8-1 through 8-3.

8.4. Measures of Skill:

a. AWS Aerospace Sciences uses the Brier Score as the standard measure of the skill of probability forecasts. The score values can range from zero (perfect forecast) to two (worst possible forecast). The Brier Score can be resolved into two components:

(1) Sharpness: This is a measure of forecast certainty and is due strictly to the distribution of forecasts without regard to observed events.

(2) Bias: This has the connotation of reliability and is a measure of how much the Brier Score would change if the over/under forecasts were forecast with the correct probability. The total Brier Score is the sum of the sharpness and bias.

b. Because AWS has not yet published standard Brier Scores for four and five category probability forecasts, there are no "bench marks" with which to compare the results shown here. However, based upon experience of the National Weather Service in their verification of probability forecasts, Brier Scores in the range of 0.3 to 0.5 would appear to constitute acceptable results.

8.5. Analysis of Results:

a. In analyzing the verification statistics in an attempt to make a subjective judgement regarding "what went right and what went wrong," a review of the three figures indicates that the Brier Scores were generally worse at the 06-, 18-, and 30-hour forecast times than at 12-, 24-, and 36-hours. This is likely due to two causes:

(1) The dependent data set upon which the system was developed consisted of forecast fields valid at 00Z and 12Z as stated in a previous chapter. These times are essentially midnight and noon in central Europe. These same data base times were used by the numerical models to generate the forecast meteorological variables from which the probability forecasts were produced. No dependent numerical model forecasts for use as predictor data were generated for the "off-time" hours of 06 and 18Z; consequently, the probability system generally performed better at those times which were compatible with its development data set.

(2) The time display of the Brier Scores in the three figures reflects a "saw tooth" appearance. Because this peculiar curve is prominent on each graph, a check of the distribution of the categorized verification observations revealed that, overall, there were significantly more observations of poor weather at 06Z and 18Z than at 00Z and 12Z. These 06Z-18Z observations verified the 06-, 18-, and 30-hour forecasts while the 00Z-12Z observations verified the 12-, 24-, and 36-hour forecasts. As an example, for the three lowest categories (i.e., ceilings less than 1000 feet and visibility less than three miles) there were 15% more observations of low visibility at 06Z-18Z than at 00Z-12Z. On the "good weather" side, the upper two categories, there were slightly more (4%) observations of high ceilings and 22% more observations of good visibility at 00Z-12Z than at 06Z-18Z. Thus, it can be seen that the hours of 06Z and 18Z, which are dawn and dusk times respectively, reflect the higher frequency of stratus and fog common in the mountain/valley terrain of central Europe. This time dependency of the poor weather conditions, more than anything else, seems to account for the "saw toothed" effect evident in the graphs. The persistence line on each figure is derived totally from verification observations and vividly displays the "saw tooth" effect with the highest Brier Scores (poorest forecasts) at the 06-, 18-, and 30-hour points.

(3) There may possibly have been other causes which contributed to the generally poor results indicated by the Brier Scores; however, the higher frequency of poor weather at the off-time hours as stated above masked any other problems.

b. In the five category separate verification of ceiling and visibility (Table 8-1 and Figure 8-1), the TRP Blended forecasts scored significantly better than persistence after the 6-hour point. Overall, the system produced better scores for ceiling forecasts than for visibility forecasts.

However, an anomaly exists in the ceiling scores at 18- and 30-hours where the scores were better than those at 12-, 24-, and 36-hours. This disparity between the results of the ceiling and visibility forecasts is possible because, during September, the poorest weather was caused more by restrictions to visibility than by low cloudiness. When one compares the individual models for each forecast time period and parameter in Table 8-1, marked differences in skill are apparent. In general, TFM, OHM and MCO outperformed BLM, TRAJ and TRP. Reasons for this are discussed in Chapter 4. A measure of the true degree of predictability can be inferred from the analysis of the Brier sharpness and Brier bias scores. BLM, TRAJ and TRP show considerable error in the bias. The exact cause of this (small data sample, lack of seasonal adjustment, etc.) cannot be determined, but proper development of the forecast equations should eliminate a bias error of this magnitude. The sharpness scores then reflect the potential predictability of this model. When these are examined, one notices the TRAJ and TRP models have potentially more skill than the TFM, OHM, and MCO.

c. To make a comparison between automated forecasts and manual, subjective forecasts, the separate ceiling and visibility forecasts were combined statistically into a single joint probability in four categories. Forecasts for the first four forecast periods were then compared with similar forecasts prepared by 2d Weather Wing units. Again, persistence forecasts were made to provide a basis for comparison. As was the case with the five category forecasts, both persistence and the 2WW subjective forecasts scored better at the 6-hour point. Here again, because of reasons previously stated, the dependent sample contained no forecast fields valid at 06Z-18Z, and this is reflected in the results. The 2WW units used detailed conditional climatology tables as an aid in their subjective forecasts. These tables account for the known diurnal variability of the weather. The diurnal variation was modeled in the "CLIM" program through the cos (TOD) and sin (TOD) terms. Diurnal variation was ignored in the predictors except in the MCO model. From the 12- to 24-hour points, the TRP Blended model forecasts improved to the point where they scored better at 18-hours and were comparable at 24-hours to the 2WW forecasts. There were no 2WW forecasts at 30- and 36-hours. This is again indicative of patterns that have been observed in the verification of other MOS-type forecasts wherein the manual subjective forecasts perform better up to 12 hours. Thereafter, the purely automated forecasts perform as well as or better than the manual ones. This is significant when consideration is made for problems encountered and shortcuts taken, identified in Chapters 2 and 4, to put the TRP system into production.

d. Because the task of the exercise was to provide forecast MSIs, it was decided to check on how well the MSIs verified at a test location by using the MSI forecasts, the Army operational probability of success thresholds (OPST), and the observed weather. The German station Kitzingen, EDIN, was chosen because it was located at the center of the exercise area. The observed ceiling and visibility information was applied to the Army OPST values for each of the four scenarios to generate an "observed" MSI. Given a forecast and observed MSI, the Brier Score was computed. The observed data were also used to compute a "climatology" MSI from the USAFETAC climatic data and a similar persistence MSI. The mean Brier Score curves shown on Figure 8-3 indicate that the TRP Blended Model performed significantly better on the four exercise scenarios' MSIs than it did on the AWS PEP category weather probabilities. At the 12-, 24-, and 36-hour points, the TRP and climatology produced virtually identical forecasts. This is probably attributable to the fact that EDIN is well located within the exercise area where the USAFETAC modeled climatology "fit" reasonably well -- at least at the 12-, 24-, and 36-hour points.

8.6. Conclusion. The verification results, although not as good as hoped, demonstrate that fully automated forecasts can provide useful decisionmaking assistance. Apparent problems were: insufficient data for development of stable equations, available development data was for a different time of year, and inadequate time for equation development and testing. Despite these problems, the TRP Blended Model forecasts scored better at 18 hours, and were comparable at 24 hours to the 2WW forecasts.

Table 8-1.

AFGWC/WPA, OFFUTT AFB, NEB 68113 - UNCLASSIFIED

REFORGER 76 VERIFICATION STATISTICS

ANS 5 CATEGORY DATA FOR CEILING AND VISIBILITY SEPARATELY

	06C			06V		
	BLM	OHM	TFM	BLM	OHM	TFM
NUMBER OF CASES	336	336	336	374	374	374
NUMBER OF HITS	93	153	167	112	124	109
PERCENT CORRECT	27.2	45.5	49.7	29.9	33.2	29.1
BRIER SHARPNESS	.54	.62	.63	.36	.71	.52
BRIER BIAS	.43	.05	.02	.33	.05	.04
BRIER SCORE	.97	.67	.65	1.04	.76	.92

	12C			12V		
	BLM	OHM	TFM	BLM	OHM	TFM
NUMBER OF CASES	342	342	342	380	380	380
NUMBER OF HITS	78	147	161	133	188	203
PERCENT CORRECT	22.8	43.0	47.1	35.0	49.5	53.4
BRIER SHARPNESS	.61	.64	.65	.72	.68	.68
BRIER BIAS	.30	.06	.03	.04	-.02	-.03
BRIER SCORE	.91	.70	.68	.77	.68	.67

	18C			18V		
	BLM	OHM	TFM	BLM	OHM	TFM
NUMBER OF CASES	338	338	338	377	377	377
NUMBER OF HITS	133	165	162	163	168	162
PERCENT CORRECT	39.3	48.8	47.9	43.2	44.6	43.0
BRIER SHARPNESS	.50	.61	.60	.63	.61	.60
BRIER BIAS	.10	.02	.03	.11	.12	.14
BRIER SCORE	.76	.63	.63	.74	.73	.74

	24C			24V		
	BLM	OHM	TFM	BLM	OHM	TFM
NUMBER OF CASES	341	341	341	380	380	380
NUMBER OF HITS	145	148	153	166	192	193
PERCENT CORRECT	42.5	43.4	44.9	43.7	50.5	50.8
BRIER SHARPNESS	.50	.61	.59	.69	.71	.70
BRIER BIAS	.29	.06	.07	.02	-.03	-.03
BRIER SCORE	.79	.67	.66	.71	.68	.67

	30C			30V		
	BLM	OHM	TFM	BLM	OHM	TFM
NUMBER OF CASES	336	336	336	376	376	376
NUMBER OF HITS	159	167	168	155	184	184
PERCENT CORRECT	47.3	49.7	49.6	41.0	49.2	49.2
BRIER SHARPNESS	.67	.67	.66	.74	.74	.74
BRIER BIAS	.04	.02	.02	.05	.04	.04
BRIER SCORE	.71	.69	.68	.79	.78	.77

	36C			36V		
	BLM	OHM	TFM	BLM	OHM	TFM
NUMBER OF CASES	340	340	340	380	380	380
NUMBER OF HITS	139	144	144	153	200	204
PERCENT CORRECT	40.9	42.4	42.4	40.3	52.6	53.7
BRIER SHARPNESS	.66	.66	.65	.69	.69	.68
BRIER BIAS	.06	.05	.03	.11	-.03	-.03
BRIER SCORE	.72	.71	.70	.70	.66	.65

MODEL IDENTIFICATION --
 BLM - BOUNDARY LAYER
 TFM - TERMINAL FORECAST
 OHM - OBJECTIVE HWD
 TRJ - TRAJECTORY
 MCO - MARKOV-CLIMATOLOGY-OBSERVATION
 TRP - TRANSNORMALIZED REGRESSION PROBABILITY
 (THE BLENDED MODEL USED TO MAKE THE
 ACTUAL MSI FORECASTS)

OTHER IDENTIFICATION --
 06: 12, ETC. -- FORECAST VALID TIME (Z)
 C - CEILING
 V - VISIBILITY

Table 8-2.

AFGWC/WPA, OFFUTT AFB, NEB 68113 - UNCLASSIFIED

REFORGER 76 VERIFICATION STATISTICS

AWS 5 CATEGORY DATA FOR CEILING AND VISIBILITY SEPARATELY

PERSISTENCE FORECASTS

	06C	06V	12C	12V	18C	18V	24C	24V	30C	30V	36C	36V
NUMBER OF CASES	318	345	323	371	315	365	320	370	314	366	316	370
NUMBER OF HITS	192	201	179	171	162	143	169	210	130	162	139	159
PERCENT CORRECT	60.4	55.1	55.4	46.1	51.4	39.2	52.8	56.8	43.9	44.3	44.0	43.0
BRIER SHARPNESS	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
BRIER BIAS	.79	.90	.89	1.00	.97	1.22	.94	.86	1.12	1.11	1.12	1.14
BRIER SCORE	.79	.90	.89	1.00	.97	1.22	.94	.86	1.12	1.11	1.12	1.14

Table 8-3.

AWS 4 CATEGORY CEILING/VISIBILITY JOINT PROBABILITY DATA

	06HR		12HR		18HR		24HR		30HR		36HR	
	TRP	2WW	TRP	2WW	TRP	2WW	TRP	2WW	TRP	2WW	TRP	2WW
NUMBER OF CASES	335	344	339	353	337	345	340	353	336	334	339	339
NUMBER OF HITS	141	212	183	248	219	282	218	249	155	223	223	223
PERCENT CORRECT	42.1	61.6	54.0	70.3	65.0	81.6	64.1	70.5	46.1	65.8	65.8	65.8
BRIER SHARPNESS	.49	.35	.54	.36	.44	.36	.51	.34	.60	.56	.56	.56
BRIER BIAS	.28	.20	.05	.09	.10	.22	-.04	.11	.00	-.07	-.07	-.07
BRIER SCORE	.77	.55	.59	.45	.54	.58	.47	.45	.60	.49	.49	.49

NOTE - NO 2WW SUBJECTIVE FORECASTS AVAILABLE FOR 30, 36 HRS.

Table 8-4.

AWS 4 CATEGORY CEILING/VISIBILITY JOINT PROBABILITY DATA

PERSISTENCE FORECASTS

	06HR	12HR	18HR	24HR	30HR	36HR
NUMBER OF CASES	317	322	314	318	313	314
NUMBER OF HITS	203	220	175	230	181	203
PERCENT CORRECT	64.0	68.3	55.7	72.3	57.8	64.6
BRIER SHARPNESS	.00	.00	.00	.00	.00	.00
BRIER BIAS	.72	.63	.89	.55	.84	.71
BRIER SCORE	.72	.63	.89	.55	.84	.71

Table 8-5.

AFGWC/WPA, OFFUTT AFB, NEB 68113 - UNCLASSIFIED

REFORGER 76 VERIFICATION STATISTICS

BRIER SCORES FOR
OPERATIONAL FORECAST MISSION SUCCESS INDICATORS FOR STATION EDIN

MISSION NR FCST TIME	1			2			3			4		
	B	P	C	B	P	C	B	P	C	B	P	C
06HR	.1383	.1728	.1143	.1102	.1406	.1061	.2156	.2778	.1817	.0700	.0876	.0583
12HR	.0003	.0259	.0328	.0001	.0361	.0000	.0004	.0508	.0036	.0476	.0565	.0509
18HR	.1291	.1681	.1107	.1124	.1562	.1030	.2028	.2703	.0036	.0518	.1199	.0511
24HR	.0008	.0266	.0029	.0002	.0371	.0000	.0008	.0513	.0039	.0422	.0898	.0476
30HR	.1620	.1777	.1270	.1352	.1651	.1134	.2497	.2857	.2026	.0870	.1160	.0791
36HR	.0021	.0273	.0028	.0006	.0380	.0000	.0031	.0526	.0036	.0407	.0853	.0513
COMPOSITE	.0720	.1008	.0601	.0549	.0903	.0487	.1089	.1622	.0927	.0550	.0803	.0531
NR CASES	216	216	216	240	240	240	222	222	222	234	234	234

COMBINED
SCORES ALL
TIMES AND
MISSIONS

TOTAL CASES 912

MODEL IDENTIFICATION --
B - TRP BLENDED FORECAST
P - PERSISTENCE FORECAST
C - ETAC CLIMATIC FORECAST

COMPOSITE

B	P	C
.1355	.1747	.115
.012	.042	.0145
.124	.1786	.11
.011	.051	.0138
.1585	.186	.1291
.0135	.051	.0146

5 CATEGORY VERIFICATION

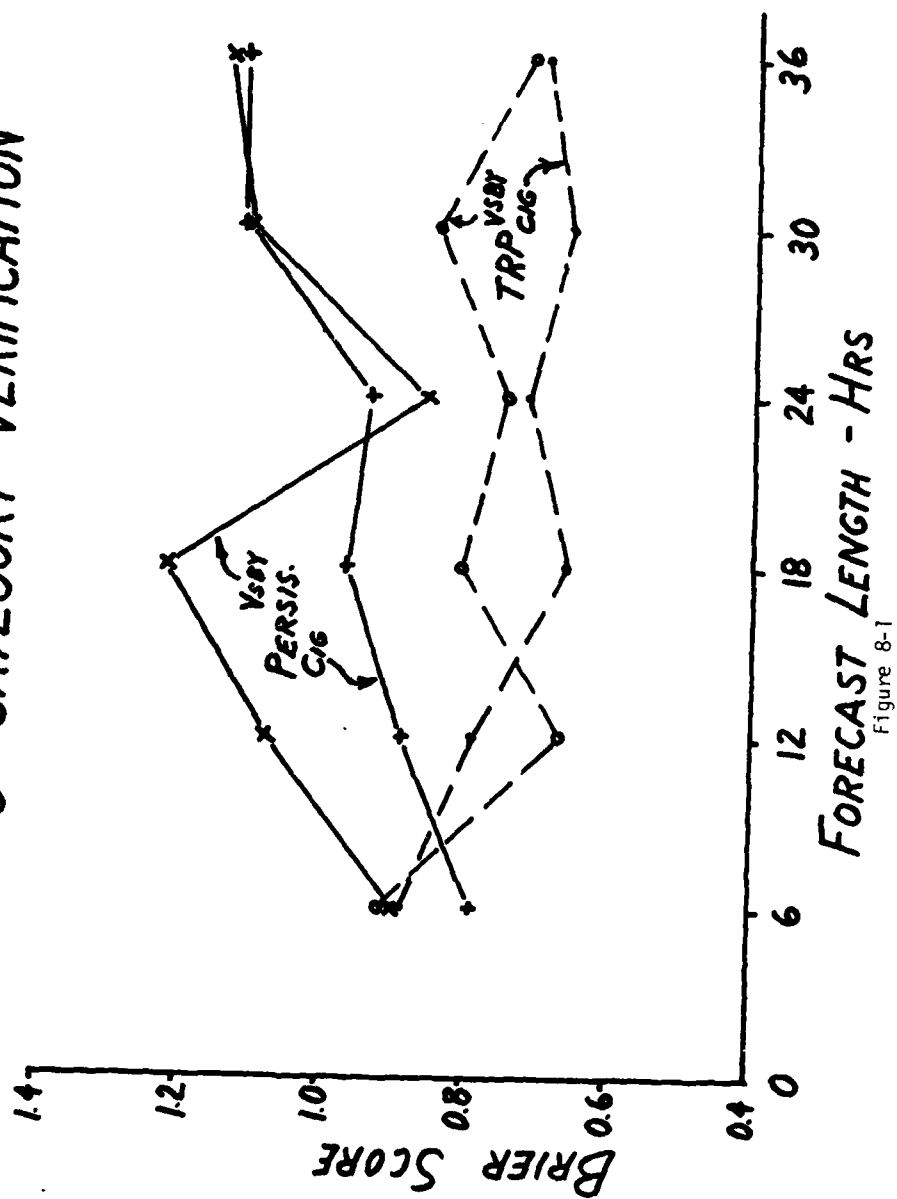


Figure 8-1

4 CAT. COMB. CIG-VSBX VERIF.

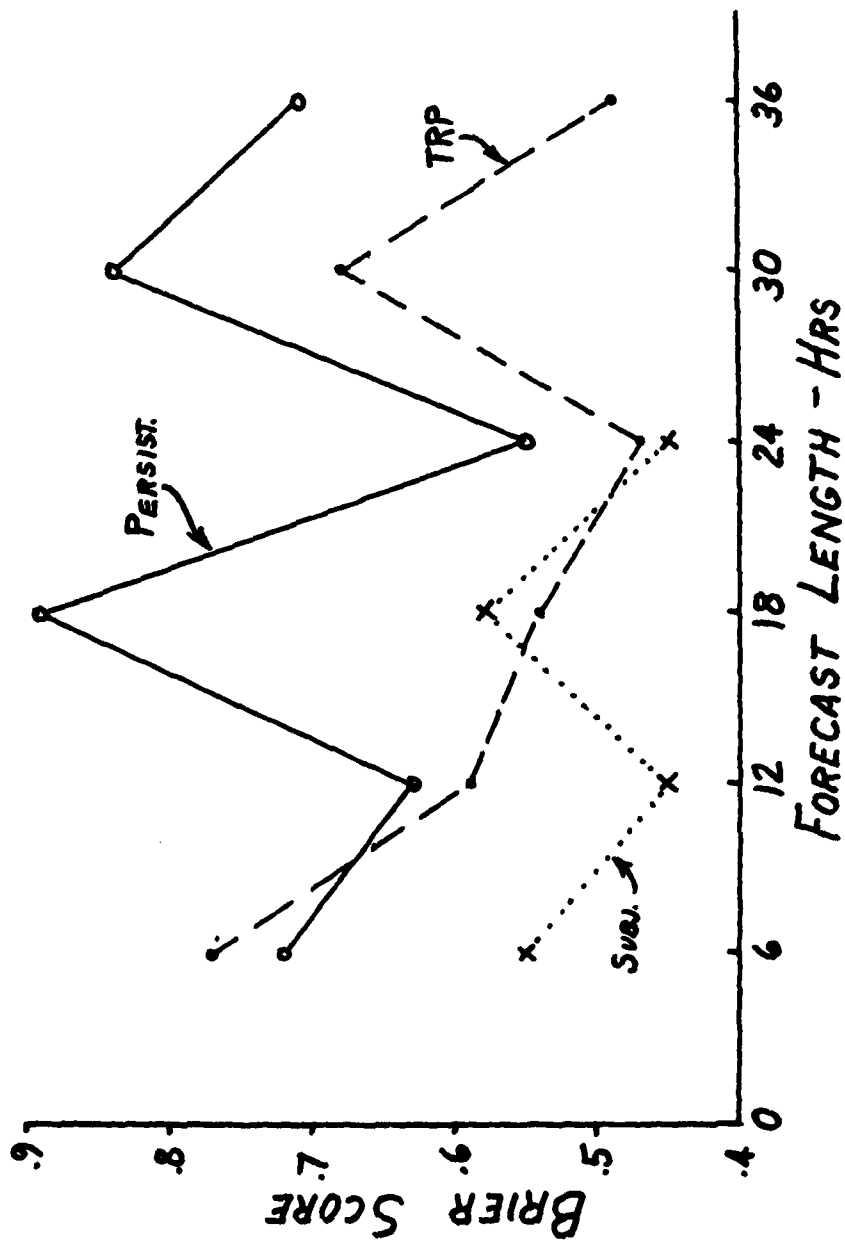


Figure 8-2

COMPOSITE OF ALL MISSIONS STATION EDIN

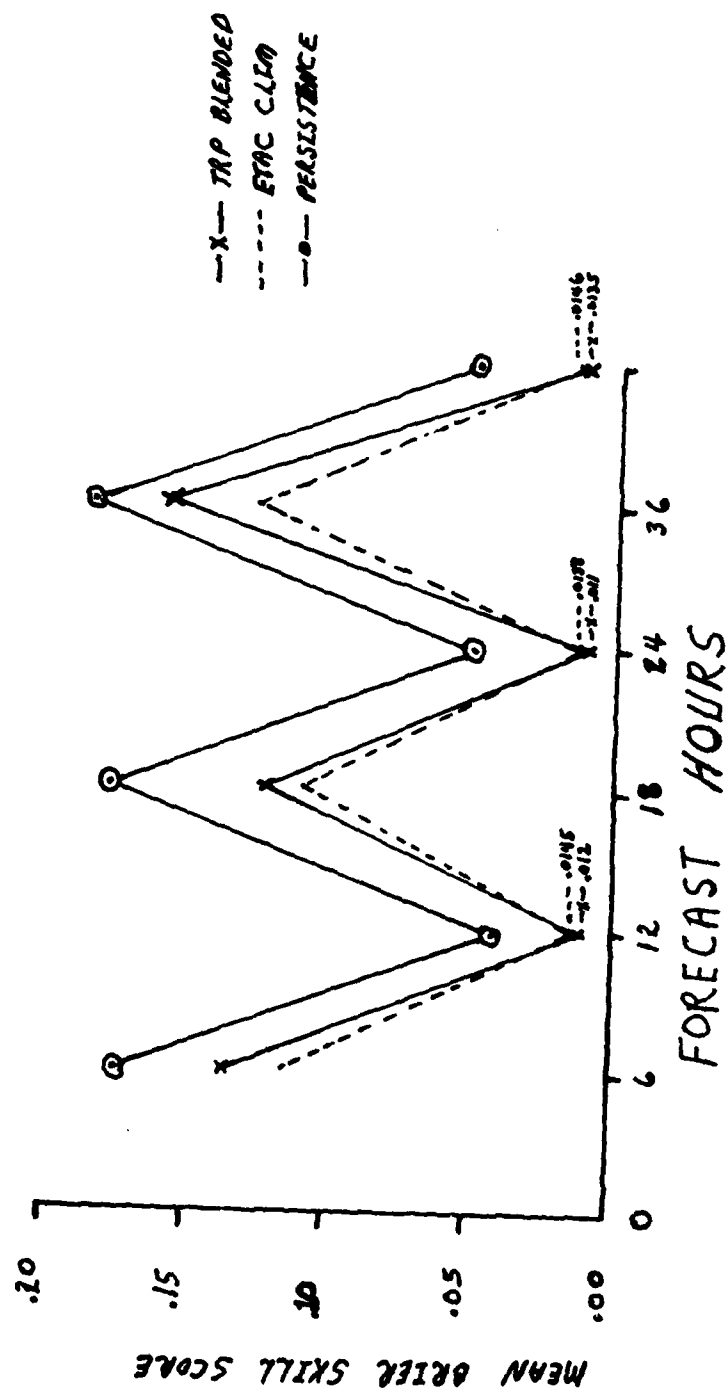


Figure 8-3

Chapter 9*

OPERATIONAL EVALUATION

9.1. Introduction. Operational evaluation of the MSI test is divided into three major sections: Communications, Operational Verification, and Feedback and Recommendations. In the first section, each method used to transmit MSI data to field units is evaluated. The second section evaluates the FMSI product based on the outcomes of customer decisions. The third section contains specific feedback from both Army decision makers and staff weather officers (SWOs) followed by recommendations from 2WW for improving the product.

9.2. Communications. Since units in the field environment are not directly connected with the Automated Weather Network (AWN), special communications systems must be established to transmit weather data from AFGWC to these units. One of the objectives of the REFORGER 76 MSI test was to evaluate this communications link. To this end, the links from AFGWC to USAREUR/WSU at Heidelberg and from USAREUR/WSU to the field units are addressed in this section.

9.2.1. Receipt of MSI Data at USAREUR/WSU. The landline interface with the AWN was accomplished by the 1st Combat Communications Squadron (1CMBTCS). Since the MSQ-10 intercept van was not available, the Tactical Weather Analysis Center (TWAC) intercept van was used in its place. This was the first major European exercise for the TWAC system and the system accomplished its mission. However, several difficulties encountered with the TWAC are worth mentioning.

a. The TWAC teletype reperforator caused several problems.

(1) The reperforator in the TWAC was not compatible with the USAREUR/WSU's equipment. Specifically, the reperforator tape was too narrow for the WSU transmitting device. This meant that one person was dedicated full time to guiding tapes through the WSU machine. Even so, many transmissions became garbled when tapes slipped off-center.

(2) The TWAC reperforator did not print characters on the tape. The result was an editing nightmare. To prevent time delays for MSI bulletins, an MSI tape was transmitted on WSU equipment "in the blind" while simultaneously cutting another tape. This also contributed to the number of garbled messages sent to the field since the WSU could not ascertain prior to transmission if a bulletin had been received garbled by the TWAC.

(3) For unknown reasons, the TWAC reperforator frequently jammed on long bulletins (such as MSI bulletins).

b. A very distinct deficiency of the TWAC system was its inability to intercept Deutsches Wetterdienst (DWD) products. The TWAC receives high frequency and DWD transmits on a low frequency.

c. Some supply problems were encountered. Such items as teletype paper, reperforator tape, and helix wires were not compatible with WSU equipment and therefore could not be borrowed.

d. The large quantities of fuel (JP-4) needed to run the TWAC generators will not be available from Army sources during a real war. However, the TWAC was designed to operate near a TACC (i.e., near an airfield).

9.2.2. Receipt of MSI Data at Field Units. Four systems were used to transmit FMSI products to deployed SWOs during REFORGER 76. The USAREUR/WSU was the source for the first three systems discussed below. As a test for transmitting data directly from AFGWC to field units, the AUTODIN system (Automated Digital Information Network system, a common user communications circuit) was also tried.

a. High frequency radio teletype via the USAREUR Weather Network (UWN). This is a teletype only, 60 words per minute system that relays data between the WSU and deployed units. The completely realistic nature of the REFORGER 76 exercise in terms of frequent, fast moving deployment of tactical forces attested to the emphasis that must be placed on the UWN as the primary method of getting FMSI data to the tactical Army commander. The bulletins transmitted via UWN were received with occasional garbling. Indeed, the UWN message capture rate exceeded 80% for REFORGER 76 and was the highest of any REFORGER exercise. Table 9-1 is a listing of UWN message receipt times for several 7WS units.

*This chapter incorporates Reference 5.

b. Teletype via Army Command and Area Communications System (ACACS) multi-channel. Teletype transmission of weather data from WSU to the field units via ACACS met with only limited success. This system did prove to be less susceptible to garbling than the UWN. However, the initial establishment of multi-channel links from WSU to Corps required about 48 hours, and the link from Corps to Division required 72 hours or longer. Because of the frequent moves by division and regiment SWOs, ACACS teletype was only intermittently available at division tactical locations and was not feasible at the regiment.

c. Facsimile via ACACS multi-channel. The lack of truly tactical facsimile equipment has been a longstanding problem in Army weather support. The Muirhead facsimile receiver (MUFAX) is used because no other equipment is available. It is a sensitive, heavy, tube type piece of equipment that cannot withstand the hardships of field use. As a result, reception of ACACS facsimile products was poor at best (24% capture rate at V Corps, 40% at VII Corps, none received at lower levels). Perhaps, the major problem is that no maintenance on the MUFAX is available in the field. Since the SWO typically deploys with his airfield's spare MUFAX recorder, he has no backup set either in the field or back in garrison. The nonavailability of multi-channel facsimile links below Corps prevented testing of facsimile retransmissions from corps to divisions and regiments.

d. Messages via AUTODIN. The test revealed that AUTODIN was not a satisfactory system for providing timely FMSI bulletins to tactically deployed weather units. While the Army message centers received the bulletins in an acceptable time frame (see Table 9-1), the main problem was further distribution to the SWO. In most cases, this distribution took from two to six hours. In addition, messages were not always delivered to the addressee despite the seemingly correct use of tactical routing indicators.

9.3. Operational Verification. Operational verification addresses the quality of AWS support from the customer perspective. It is a means to document the extent that weather support contributes to customer effectiveness. During REFORGER 76, SWOs were encouraged to identify their Army customer's decisionmaking points and then to record weather forecasts given the customer, the decision made, and the outcome of the decision. Of the 1663 decisions recorded by the 7WS/SWOs, most (1649) were recorded by the SWOs to the 2ACR (1392 decisions) and the 3AD (257 decisions). Because of this, the bulk of the analysis will use data reported by the 2ACR/SWO. According to the SWOs, go decisions were made only when favorable forecasts were given. In addition to the Army units, the Allied Tactical Operations Center (ATOC) participated in the MSI test.

9.3.1. 2ACR. The unit supporting the 2ACR did an outstanding job of collecting operational verification data during the test. Not only were decisions and outcomes recorded by scenario, but the forecast length used was also noted. This indicated that the most frequently used forecasts were the ones of 24 and 30 hours length. The decisionmaking timetable at this unit for these scenarios was for a late afternoon or early evening decision on operations to be conducted the following morning.

a. Data.

Scenario I

Operator Decision

O b s e r v e d		Go	No Go
	Favorable	236	7
	Unfavorable	85	18

U
b
s
e
r
v
e
d

Scenario II

Operator Decision

	Go	No Go
Favorable	168	84
Unfavorable	36	36

U
b
s
e
r
v
e
d

Scenario III

Operator Decision

	Go	No Go
Favorable	395	40
Unfavorable	51	16

U
b
s
e
r
v
e
d

Scenario IV

Operator Decision

	Go	No Go
Favorable	114	34
Unfavorable	56	16

U
b
s
e
r
v
e
d

Total for I, II, III, IV

Operator Decision

	Go	No Go
Favorable	913	165
Unfavorable	228	86

b. Analysis. Since the results of customer decisions for the four scenarios are similar, the analysis will only address the total. The same detailed analysis as was done on the total can be done for each scenario.

Possible Customer Outcomes	Customer Always Uses Forecast	Customer Ignores Forecast
Success	913 (66%)	1078 (77%)
Correct Standdown	86 (6%)	0
Abort	228 (16%)	314 (23%)
Missed Opportunity	165 (12%)	0

(1) It is impossible to draw any conclusions on the benefits of the MSI forecasts to decision maker from this analysis. The data suggests the customer would have raised his success rate and his correct decision rate (success plus correct standdowns) by ignoring the forecast product. However, this conclusion cannot be made without information on the value the customer placed on each of the four outcomes for each mission. This type of information is difficult to collect and was not specifically requested during this test.

(2) Another factor that makes conclusions from the analysis difficult is the fine tuning of the MSI model being done by AFGWC until 14 Sep. Because of this, the technical verification program used data from 14 Sep forward. The exercise ended on 17 Sep so that the bulk of operational verification data collection effort took place while the model was being changed.

9.3.2. 3AD. The 3AD SWO collected operational verification data on decisions made at the V Corps Air Field. These were helicopter operations using Scenario I (without kill factor) and Scenario III.

a. Data

Scenario I

Operator Decision

		Go	No Go
O b s e r v e d	Favorable	177	0
	Unfavorable	24	0

Scenario III

Operator Decision

		Go	No Go
O b s e r v e d	Favorable	50	0
	Unfavorable	6	0

b. Analysis. Of primary importance here is that no No Go decisions were recorded. This is the same as ignoring the forecast. However, the 3AD/SWO noted that the FMSI for Scenario I was either "8" or "9" for all of these go decisions and Scenario III had "H" for all these decisions. The aborts occurred on 9 Sep when unforecast bad weather moved in. The success rate for Scenario I was

88%; for Scenario III, 89%. Another possible explanation for only go decisions being recorded is that the SWO was not monitoring the real decision point.

9.3.3. Other Units. Few decisions on these scenarios were made at USAREUR, the two corps, and the other divisions. The consensus was that these decisions are made at lower echelons, most probably at battalions. Several decisions on airborne assault (Scenario III) were recorded and the SWOs attempted to use the weather information in Scenarios III and IV for such missions as paradrop and smoke release operations.

a. Data

		<u>All Scenarios</u>	
		Operator Decision	
C o n d i t i o n s		Go	No Go
	Favorable	8	0
	Unfavorable	5	1

b. Analysis. All known decisions, except those made at 2ACR and 3AD, are recorded here. While this is a small sample, these data show a relatively high abort rate, perhaps indicating the forecast model was overly optimistic. A close analysis of the aborts revealed that most were early morning airborne assaults that were cancelled after a scout helicopter determined that unfavorable conditions existed.

9.3.4. ATOC. There was considerable resistance from the customer at the ATOC to use the MSI product. The problem areas were a lack of understanding of MSIs, the inclusion of kill factors, and disagreement between the MSI forecast and the mission control forecast that was produced by ETFU.

a. It was determined that the ATOC plans personnel would be the ones most likely to use the MSI products. Their job was to plan the next day's missions for either VFR or IFR and for weapons load. MSI briefing forms were prepared daily; the forms also included space for customer feedback (i.e., missions into this area were scheduled for VFR, into that area for IFR). No decisions were recorded by the plans staff. After the exercise, the SWO compared IFR missions scheduled and weather forecasts but no correlation was found. It was pointed out that, to the Air Force, one of the objectives of the exercise was to maximize training. Therefore, most flights were scheduled VFR, since this allowed four aircraft to be scheduled into the exercise area, versus one under IFR conditions.

b. The ATOC customer liked the MSI concept and, in particular, felt the grid size and spacing were good. However, the product probably would have been used much more if it had included weather only.

9.3.5. Conclusion. REFORGER 76 represented the first large scale effort to collect data for the operational verification program. This effort proved several things. First, SWOs should use SMSIs to help the customer determine his critical probability. This may change for each mission. Second, a valid analysis of operational forecasts will require that data be grouped by threshold and also by lumping together go/no go forecasts using the same critical probability.

9.4. Feedback and Recommendations. This section contains feedback from Army decision makers about the utility of the MSI products and from 7WS Staff Weather Officers about problems encountered when using the products. Each deficiency is followed by a 2WW recommendation to resolve it.

9.4.1. Feedback from Army Decision Makers. In general, the Army commanders and key staff liked the idea of combining all "weather" into one number, in probabilistic format, for each grid point. To a large extent the acceptance of the MSI products depended on the decision maker's perception of how sensitive his operation was to the weather. However, the test revealed several desires of the Army key personnel.

a. Most want a "weather only" MSI. The Army commander is forced to operate under many operational constraints, most of which are dependent on the immediate threat. When an MSI includes other factors (such as a weapon system effectiveness rate), its use to the commander is automatically restricted to that specific scenario. He may have other options with the same weather threshold. Thus, the Army commander wants the probability that the weather will be favorable for certain thresholds and he will apply his own kill factor. For the near future, this will likely be a "seat-of-the-pants" decision, but ultimately the customer may have his own computer loaded with the performance factors of his various options and the weapon systems which threaten him. A "weather-only" MSI will also negate the response sometimes given by Army decision makers that they could not use the product because they did not agree with the kill factor used in this test. Further, MSIs which include kill factors for all possible contingencies (i.e., stationary tank, moving tank, hidden tank, etc.) would saturate the communications system between the WSU and the field units. Until such time that a system such as the World Wide Military Command and Control System (WWMCCS) can provide the tactical Army commander with a full range of MSI products with kill factors, the product should contain weather criteria only. This is not possible when customer success rate varies with weather as in the close air support case.

RECOMMENDATION 1. Make MSIs void of kill factors unless otherwise requested by the customer.*

b. Although the weather threshold criteria used in these scenarios were applicable to the types of operations conducted in REFORGER 76, it is not possible at this time to establish these criteria as the ones for which routine MSI products should be provided. As mentioned earlier, few decisions were made on these scenarios at corps and division level. In the future, SWOs at all levels should play a major role in choosing the scenarios for which MSI products are requested. For example, several additional scenarios which would have been useful during REFORGER 76 were personnel paradrop and nuclear/chemical operations by both friend and foe.

RECOMMENDATION 2. Insure that SWOs interface with Army decision makers to select the scenarios needed by the customer for exercise MSI products.

c. Experience gained while using the MSI products at all Army echelons revealed the need for increased grid point density to adequately depict the variability of weather in the Army's European Area of Operations (AO). MSIs must be provided on a smaller grid to serve the Army on the scale in which they operate.

RECOMMENDATION 3. Provide MSI products on a grid with a maximum spacing of 5 km. Determine the feasibility of using the Army's coordinate grid system.

d. Several new or extended uses of MSIs were identified.

(1) The V Corps/G2 and IID/G2 were interested in using MSIs to portray enemy capabilities. This means expanding the area covered by the MSI product.

(2) Some units desire MSI products for selected scenarios (to be determined by 7WS SWOs) for the USAREUR AO for all months.

(3) The MSI products should be tested during monthly division exercises and in all USAREUR major training areas to allow maximum training for SWOs and Army users.

RECOMMENDATION 4. Make MSI products available for the USAREUR area of interest for all months.

9.4.2. Feedback from 7WS/SWOs. The extent to which the SWOs used the MSI product depended on what their customer wanted. As was seen in the Operational Verification Section, this varied greatly throughout 7WS. Some units had permanent displays of FMSI bulletins in the command post, while other SWOs used the MSIs as just another forecast tool. The SWOs supplemented the feedback from their customers with some specific comments of their own. These comments fall into two general areas: drawbacks or problems associated with the operational use of the MSIs and problems associated with the FMSI bulletin format.

a. The 2WW did not receive the complete MSI information early enough for them to fully understand all the MSI products that were available. The main problem was assisting the Army decision maker to choose a critical probability for each of the scenarios. One valuable aid for selecting critical probability, a USAFETAC produced book of SMSIs, was handcarried to 7WS at the beginning of the exercise. Most SWOs saw the book during the exercise but could not incorporate this information

*See note at end of this chapter.

into their operation at that late stage. As a result, Army commanders found it difficult to translate "gut feeling" into a critical probability for go/no go decisions and weathermen were inexperienced at thresholding FMSI values against CMSI values as a substitute for customer critical probabilities. Additional data, which were provided as the exercise began (but were not used), included information on the effect increasing the number of weapon systems has on the probability of success and a method for computing success, if the enemy is allowed to shoot back.

RECOMMENDATION 5. Make CMSI and SMSI data available to SWOs well in advance of an exercise so that the Army customer has sufficient time to establish critical probabilities. In addition, provide information on the MSI algorithm and model details as early as possible.

b. Speed and reliability of tactical communications systems will prove to be the primary limiting factors in providing FMSI support to the Army commander. For REFORGER 76, most field units received the SMSI bulletins after the six-hour forecast was valid (field units received 30 percent of the FMSI bulletins less than six hours after data base time, Table 9-1). Thus, the SWOs felt the six-hour forecast had no use except as a comparison with observed weather. At division and higher levels, the six-hour forecast was not considered necessary. At lower echelons, where immediate operational decisions are made, the six-hour forecast is most important.

RECOMMENDATION 6. Transmit FMSI bulletins with sufficient leadtime to effect use of six-hour forecasts at battalion level and below. Since the WSU retransmits bulletins to deployed units, the goal should be bulletin arrival at the WSU by 4½ hours after data base time. If this is not feasible, delete the six-hour forecast from the bulletin in order to conserve communications time.

c. The FMSI's apparent lack of consistent forecasting quality generated some concern. It seemed a matter of course that Scenarios I, II, and III (rare event weather criteria) were too optimistic and Scenario IV was too pessimistic. Specific instances were 2, 8, and 15 Sep when the FMSI data did not call for significant deterioration on the following day; yet, in each case, frontal systems on the next day lowered ceilings and visibilities. Scenario IV consistently reflected low probabilities of success during good weather (many sorties were flown during periods with low FMSI forecasts) and Scenario IV did not change appreciably when adverse weather moved in. (Note that the low kill factors for Scenario IV forced the MSIs to be less than 0.5 in perfect weather. Severe additional penalties occurred for ceiling or visibility probabilities less than 9000'/5 miles. See Table 7-1.) SWOs thought that meteorological goodness should have been proven before the MSI products were used for as important an exercise as REFORGER (even in a test). It appeared to the SWOs that the FMSI may have been tied too closely to the CMSI (i.e., the algorithm was too insensitive to forecast model input). However, this was expected. The FMSI for each point depends partly on its climatology. As forecast length increases, model output weighting decreases while climatology weighting increases. As pointed out previously, the climatology used needed improvement.

RECOMMENDATION 7. Improve the climatological input to MSIs through better data and improved modeling.

d. The length of the MSI bulletin and inherent communication problems presented occasional interpretation problems. Retransmission of FMSI bulletins because of garbling or because of a unit being on the move severely reduced the circuit time available for other data transmissions. To optimize the effectiveness of the tactical communications system, several recommendations are provided to minimize the effect of garbled, skipped, or overlined data and to facilitate rapid location of specific data points. Communications time reduction is especially important if more scenarios are added, (RECOMMENDATION 2); grid spacing is reduced, (RECOMMENDATION 3); and grid area is expanded, (RECOMMENDATION 4).

RECOMMENDATION 8. Assign letters for each row and numbers for each column.

RECOMMENDATION 9. Use a character fill-in for grid point references where FMSI data is not required rather than grouping MSIs.

RECOMMENDATION 10. Use a numeric "0" vice "H" to indicate MSI values 91-100%, since an "H" alpha character corresponds to a "STOP" function in the upper case on the teletype. This would prevent deactivation of the teletype.

RECOMMENDATION 11. Develop a system to summarize the printing on occasions when FMSI values are uniform across the grid. Some proposals are:

a. Use a plain language "No sig wx" when values throughout the grid are "9" or "0" (RECOMMENDATION 10).

b. List only low values (blanks would mean "9" or "0").

c. Print the first number in a row followed by blanks to mean the same number is valid across that row.

RECOMMENDATION 12. Use an additional character following the MSI value at each grid point to show customers and SWOs what weather parameter is responsible for the low MSI value, e.g., 3C4V where "C" is ceiling and "V" is visibility.

9.5. Summary. This limited MSI test demonstrated that MSI products, when combined with conventional weather support, have potential to significantly increase the combat effectiveness of the Army. As indicated by the volume of data presented in this section, the 7WS/SWOs dedicated enormous time and energy to the test. Since the MSI concept was well received by Army decision makers, the SWOs wanted to provide maximum feedback so that the product could be improved. Most of the feedback concerned the choice of scenarios, inclusion of kill factors, and lack of sufficient time to learn all about the product. Good planning at all levels should resolve these problems. Another area which must be addressed is the possible effect that increased use of MSIs by American forces may have on overall NATO operations. Once evaluation of MSI products is complete and their technical quality assured, the USAREUR SWO desires permanent use of tailored MSI information during monthly division and ACR field training exercises. Similar programs should be implemented for CONUS based Army units to assure the greatest possible MSI exposure to the tactical units which may be required to operate in the European combat environment.

NOTE: In late 1977 and early 1978, AWS changed policy on providing MSIs. A new term, Weather Impact Indicator (WII), was introduced which contains only weather information. The customer can use the WII to compute his own MSI.

Chapter 10

CONCLUSION

AWS expended a large amount of manpower and resources to test MSI support during REFORGER 76. This effort included development and application of new techniques and a large training program. Currently, it showed AWS ways to improve weather support to the decision maker. Although the effort pointed to a new way to provide weather support during war or contingencies, it also provided insight into the problems that could occur during this support. This new way of providing weather support has the potential to benefit AWS and its customers.

The techniques developed and applied during the exercise proved themselves despite the problems encountered. Development problems were detailed in sections 4.3 and 4.4. Even though only three months of data for a different season were available for forecast equation development and the data sample was small, the objective probability forecasts were better than or comparable to the subjective forecasts at 18 and 24 hours. This fits the pattern seen in comparing subjective forecasts with other model output statistics derived forecasts, i.e., the subjective forecast is usually better than the objective for about the first 12 hours, thereafter the objective method is better. After six hours, the probability forecasts and 2WW subjective forecast scored significantly better than persistence. Thus, the potential of this methodology for forecasting in locations where no forecaster is available or where forecaster experience is limited, is evident.

Communications problems were detailed in section 9.2. The large volume of numbers transmitted from AFGWC, i.e., 2736 each 12 hours, was a major factor causing these problems. Although recommendations were provided in 9.4 to correct communication problems, method(s) need to be used which reduce this volume of numbers. One such method is to transmit from AFGWC only the numbers generated by the first four steps of section 4.2.7, the macroscale indices. Use of this method for REFORGER 76 support would have resulted in AFGWC transmission of 108 numbers vice 2736. The numbers would have consisted of forecast ceiling and visibility distributions (2) for every six hours to 36 hours (6) for 9 macroscale grid points covering the exercise area. Steps five through nine of section 4.2.7 would then be accomplished in-theater using the "Tailor" model which includes the weapon characteristics, the climatology model, the weather thresholds, and the geographic data for the 114 grid points. This model requires little core and is very quick to run. A major advantage in addition to the reduced communications gained by using this method of providing MSI support is that new thresholds, target locations and times, or weapon kill curves could be selected and applied in-theater.

The experience gained during REFORGER 76 will reap future benefits. The forecasters involved in the exercise learned how to make probability forecasts, how to use the centralized forecasts, how to present probability forecasts to the customer, and, in some cases, how to use SMSI tables to help the customer determine his critical probabilities. This knowledge will be particularly valuable as AWS proceeds towards a MOS capability. The customer perceived the potential usefulness of forecasts in a form which consolidates the weather impacts on his missions, a form which could save him valuable time in making his decisions. In general, the customer preferred a "weather only" MSI. As noted in Chapter 9, AWS changed its policy in early 1978 on providing MSIs. AWS would provide the decision maker Weather Impact Indicators which include only weather related considerations.

A number of recommendations resulted from experience gained during the REFORGER 76 exercise. These recommendations should be considered in future exercise support and in preparing for war/contingency support. The data set used to develop forecast equations was a limiting factor. It appears that better results would have been achieved had separate equations been derived for each cycle. The Markov approximation used to develop 6, 18, and 30 hour forecast equations is probably inferior to developing regression operations on a dependent data set for these periods. In addition, predictor fields should not be restricted to those valid at the forecast time, i.e., offering only 12 hour predictor fields for 12 hour forecasts. This doesn't allow for fastness or slowness of forecast fields.

Other recommendations had to do with mathematical manipulations. To determine regression coefficients, correlation matrices at each of nine points were averaged using the Fisher Z transformation then inverted. Slightly better results were found with the dependent data when the nine points were combined, as if one station, and no direct averaging done. Also, equation development was done by transforming predictors and predictands into their END value using rank order method. However predictors were transformed using the appropriate cubic function in the operational mode. Better results might occur if dependent data were transformed using the same functions used in the operational program. Finally, post-tests using limited available data indicate that significantly better multiple correlation coefficients result by using a combination of dichotomous and continuous predictor fields.

Other problems encountered during this support were due to the climatology model. In some cases, the climatology model generated negative END slopes. This can be corrected by selecting different modeling functions. The climatology model should also be developed to generate point climatology for such variables as CFLOS, winds, clouds, soil moisture, and precipitable water since these have significant impact on operational missions. Further study is required to verify the correlation decay between observations and forecasts. This may be different than .98 for various time periods and weather elements.

The support provided during REFORGER 76 showed that MSI products have potential to increase combat effectiveness. The modern commander is faced with sophisticated weapons selection and complex decisions. He does not have time to look at large amounts of weather data to decide how his mission will be affected by weather. Providing him the impact of weather in single numbers can enhance his effectiveness as a decision maker.

This support also pointed to benefits for AWS as well as the AWS customer. At present, no objective probability forecasting system exists within AWS and only a limited subjective probability forecasting capability exists. This limited capability is not adequate to meet the weather support requirements of a war or contingency. AWS can meet these requirements when it has a MOS capability.

The REFORGER 76 experiment justifies future efforts in MSI support. Although a longer development time and more data would have improved the forecasts, they still showed skill. Moreover, possible benefits to AWS customers and to AWS were indicated by this study. AWS should use the type support provided during REFORGER 76 in other exercises and develop a full capability to support wars/contingencies based on a MOS system.

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APPENDIX A

GLOSSARY

AAFCE	Allied Air Forces Central Europe
ACACS	Army Command and Area Communications System
ACR	Armored Cavalry Regiment
AD	Armored Division
AFCENT	Allied Forces Central Europe
AFGWC	Air Force Global Weather Central
AGL	Above Ground Level
AO	Area of Operations
ATOC	Allied Tactical Operations Center
AUTODIN	Automated Digital Information Network
AWN	Automated Weather Network
AWS	Air Weather Service
BLM	Boundary Layer Model
CACDA	Combined Arms Combat Development Activity
CBR	Chemical, Biological, Radiological
CENTAG	Central Army Group
CFLOS	Cloud-Free Line-of-Sight
CINCUSAREUR	Commander-In-Chief United States Army Europe
CMSI	Climatological Mission Success Indicator
CRC	Contingency Response Capability
CRT	Cathode Ray Tube
DCS	Defense Communications System
DMAAC	Defense Mapping and Aerospace Center
DO	Operations Division
DWD	Deutsches Wetterdienst
END	Equivalent Normal Deviate
E-O	Electro-Optical
FMSI	Forecast Mission Success Indicator
IFR	Instrument Flight Rules
IPB	Intelligence Preparation of the Battlefield
JWG	Joint Working Group
MAJCOM	Major Command
MCO	Markov-Climatology-Observation Model
MI	Military Intelligence
MSI	Mission Success Indicator
MSL	Mean Sea Level
MUFAX	Muirhead Facsimile Receiver
NORTHAG	Northern Army Group
OHM	Objective Horizontal Weather Depiction Model
OPST	Operational Probability of Success Thresholds
PEP	Product Evaluation Program
REFORGER	Return of Forces to Germany
RUSSWO	Revised Uniform Summary of Surface Weather Observations
SMSI	Simulated Mission Success Indicator
SWO	Staff Weather Officer

TAC	Tactical Air Command
TACC	Tactical Air Control Center
TESS	Tactical Environmental Support System
TFM	Terminal Forecast Model
TOD	Time of Day
TR	Technical Report
TRADOC	Training and Doctrine Command
TRAJ	Trajectory Model
TRP	Transnormalized Regression Probability
TWAC	Tactical Weather Analysis Center
USAFE	United States Air Force Europe
USAFETAC	United States Air Force Environmental Technical Applications Center
USAICS	United States Army Intelligence Center and School
USAREUR	United States Army Europe
USCINCEUR	United States Commander-in-Chief Europe
UWN	USAREUR Weather Network
VFR	Visual Flight Rules
WS	Weather Squadron
WSU	Weather Support Unit
WWMCCS	Worldwide Military Command and Control System
1ID	1st Infantry Division
1CMBTCS	1st Combat Communications Squadron
2ACR	Second Armored Cavalry Regiment
2WW	Second Weather Wing
3AD	Third Armored Division
7WS	Seventh Weather Squadron

Appendix B*

CONCEPT OF CENTRALIZED SUPPORT FOR TACTICAL ARMY FORCES

1. Introduction:

a. Army commanders require weather information in a highly refined format. They expect weather decision information that is short, to the point, accurate, and timely. Much of the information traditionally provided has been too general and although meteorologically sound, has not been presented in go/no go parameters specifically related to the commanders mission. Additionally, the lack of a precise definition of go/no go parameters has not allowed the application of meteorological products. This is due in part to go/no go parameters being developed as the operation unfolds. Go/no go parameters are situationally dependent and may vary with mission urgency, threat, and other constraints. Still, the Army commander only wants that weather information that impacts his decision--no more, no less. Some critical questions for application of any kind of centralized support are: What are the family of general go/no go parameters? What time frame in the operational planning cycle are meteorological go/no go products required? What formats are necessary to interface and to be compatible with the decisionmaking data base?

b. The present concept of centralized support to the Army consists of providing general weather products, i.e., charts, maps, etc. The local forecast element then analyzes these products semi-independently at each major echelon. Weather decision information is subsequently provided by the local staff weather office via briefings, status boards, etc. In many instances, these products must be digested by the decision maker and translated mentally into his particular method and style of making decisions. Centralized support then in reality is indirect support to the decision maker. It provides the data base from which the local staff weather officer constructs his analysis and makes his forecast.

c. Reaction time is an important aspect in centralized support for the Army. Where then do centralized capabilities exceed local capabilities? Certainly, the local data bases will have to be maintained to provide near-term forecasts (0 to 24 hr). Beyond some cutoff time, centralized capabilities will exceed those of the local unit and will have more utility as time increases, i.e., 7-day forecasts, 30-day outlooks.

d. Weather decision information should relate to the probability of occurrence of specific go/no go parameters. This information allows the decision makers to immediately factor in the weather with other decision probabilities. Presently, the type of weather information a commander gets is too general and too vague. It often introduces more uncertainty and complexity into the problem. Mission success indicators give the commander a "hard number" which means more than any other type of weather information he could receive. Frequently, the commander must extract the probability of occurrence by "give and take" dialogue between himself and the staff weather officer. He gets an indication of the confidence of the forecast only through a series of iterations. Mission success indicators have the inherent quality of built-in confidence either from empirical data or from the qualitative judgment of the forecaster or analyst.

e. This concept only addresses the AFGWC functions related to the requirements for decision-related weather information. It does not include that indirect support and those products required to maintain the local data base. The majority of these requirements are fairly standard and well documented by the Tactical Environmental Support System (TESS) Study.

Go/no go criteria as applied to tactical Army missions.

a. Go/no go values have often been called "critical values" and must be properly defined. There are no universal go/no go criteria that can be defined for all Army missions. It must be emphasized that go/no go criteria are functions of weapon system capability, threat, and mission urgency. They are situationally dependent and may vary radically depending on the type of combat unit being employed.

b. Although go/no go values change, there are general descriptions that will allow the centralized facility to properly configure support concepts and procedures. The TESS Study identified

*This appendix was an attachment to Reference 2.

many of these values by user (Section IV, Appendix J) and recommended that: "Additional meteorological critical values be determined by field tests and exercises, and that they be incorporated into appropriate manuals as guidelines for tactical users." It is imperative that staff weather officers assist commanders at division and corps level in identifying and documenting go/no go values. These general values must be communicated to the AFGWC to configure the required support.

c. The concept of mission success indicators (MSI) is fundamental in this concept. When go/no go criteria are defined, MSI, either forecast mission success indicators (FMSI) or climatological mission success indicators (CMSI), are simply the probabilities of occurrence of conditions being either greater or less than specified values. Figure B-1 is a sample matrix of go/no go parameters extracted from the TESS Study and military judgment based upon experience. It must be emphasized that there are many other values, and they could change significantly as described above.

3. Assumptions.

a. Communications: To demonstrate the utility of AFGWC decisionmaking support, it must be assumed that adequate communications are available. It is recognized that present communications to any given theater may be limited by available DCS entry/exit points, theater communications system, and priority of weather circuits. The intent of this concept is to examine the AFGWC/decision maker interface, i.e., the requirement for weather decision information and the centralized capability to provide it.

b. Decision Echelons: Corp and division are assumed to be the primary decisionmaking echelon. These are the echelons at which AFGWC weather decision information is the most applicable. It is further assumed that the weather support units for these echelons will have local data bases capable of reacting to the near-term requirements for weather information. Additionally, the staff weather officer will continue to assist the commander in interpreting FMSIs and CMSIs.

c. Go/no go criteria: Sufficient resolution in the go/no go criteria must be provided to the AFGWC to configure the necessary support. Admittedly, all criteria cannot be precisely defined. At the minimum, a matrix of general requirements should be maintained which can be refined on short notice to respond to the tactical commander's needs.

4. Missions and Functions.

a. Centralized weather support will be a primary factor in the planning, deployment, employment, and redeployment of Army forces. The support provided directly to the Army, however, will be concentrated in the planning and employment phases. The deployment and redeployment weather support will be largely applied to MAC airlift in moving to/from departure, arrival, and staging locations.

b. Planning: Key to the planning function for the Army are the climatological probabilities of occurrence for numerous missions/events. The TESS Study outlines many climatological requirements in general terms. The planning will normally concentrate on events leading up to D-day, H-hour, and beyond. The commander needs to know probabilities on a fine scale (6-10 km), and is interested in probabilities of occurrence on a particular day, time of day, week, etc. Go/no go parameters must be defined in precise enough terms to allow CMSIs to be constructed. It must be emphasized that the planning function addressed here is that for deploying forces from the CONUS. It does not address that routine operational planning by division and corps staffs. That type of planning occurs within the employment phase and may also require CMSIs.

c. Employment:

(1) The bulk of weather support to the Army takes place during the employment phase. All the functions of land combat are brought into play: firepower, mobility, intelligence, combat service support, and command/control and communications. The commander and his staff employ accepted Army tactics to prosecute the battle. Major go/no go decisions related to weather are frequently made as the situation develops. Planning for future or follow-on operations is taking place continuously which require longer range forecast products and climatology.

(2) On the commander's special staff, the staff weather officer is under the supervision of the G2 (Intelligence). The G2 is responsible for management of all combat intelligence. He (with assistance of the staff weather officer) integrates weather information into combat plans and orders. The decisionmaking interface, however, includes other G-staff members such as G3 (Operations) and G4 (Logistics). Through this interface, which is called commander and staff actions, operations orders are published to execute the mission.

d. In the current combat environment, commanders and staffs are faced with massive amounts of decision related information. Therefore, the need to present weather information in a brief and concise format for immediate use is essential. The time has passed when commanders can sit back and ponder tactical plans or broad scale weather charts and slowly come to a decision. As has been stated by various Army commanders: "When I want to know about the weather, just tell me specifically how it will affect my operation." From the recent emphasis in reducing command post size and vulnerability, there will be little time available to present the traditional stand up briefings in the division/corps tactical operations centers. Additionally, if the concept of tactical command posts in the forward portion of the main battle area is implemented, the staff weather officer may be separated physically from the commander and the G2. It is imperative, therefore, to construct and present weather information in useable decisionmaking formats. FMSIs and CMSIs constructed by the AFGWC offer attractive options for improving the flow and use of weather information.

5. Profiles: Figure B-2 is a description of suggested mission profiles for the planning and employment phases. The intention is to show when products are required and what operational considerations are involved.

6. Evaluation: Selected CMSIs and FMSIs prepared by the AFGWC will be provided for use by the weather support force for REFORGER 1976. The products will be evaluated and refined for potential use in routine Army support operations. Additionally, other CONUS exercises may be identified which would allow realistic evaluation of AFGWC CMSIs/FMSIs.

Figure B-1

SAMPLE OF GO/NO GO CRITERIA FOR CONSTRUCTION OF FMSI/CMSI

<u>COMBAT FUNCTION</u>	<u>GO/NO GO PARAMETERS</u>
Airborne	1500 ft/1 mi; 13 kts sfc/30 kts drop Alt; mdt/svr turbc; svr wx; wind chill; trafficability.
Amphibious	wave ht: 4 ft, swell 5 ft; current 10 km/hour.
Armor	River stage; line-of-sight vsby: 500, 1000, 1500, 3000, 5000 m; snow depth; hvy precip (2"/24 hr); temp < 35°F; river current 4 kts.
Aviation (Ref AR 95-1)	<p>Helicopter Day: 300 ft/1 mi</p> <p>Night: 500 ft/1 mi (flat terrain) 1000 ft/1 mi (mountainous terrain)</p> <p>Fixed Wg Day: 500 ft/1 mi (flat terrain) 700 ft/1 mi (mt terrain)</p> <p>Night: 1000 ft/3 mi (flat terrain) 2000 ft/3 mi (mt terrain)</p> <p>svr turbc; icing; wind 30 kt \pm 15 kt gusts; crosswind 20 kts/90°.</p>
Infantry	Wind chill*, trafficability*.
Chem/Bio/Nuclear	Precip, sfc wind > 7 kts, temp profile, cld albedo, sky cond (all vary by agent).
Engineer	Sfc temp, precip, river current.
Artillery	Winds aloft, density profile, refractive index*.
Air Defense	Refractive index, wind, electromagnetic prop.
Intelligence (See Aviation)	Fog, precip, state of ground/sea.
Close Air Support/Recce	5000 ft/5 mi, 3000 ft/3 mi, 1500 ft/3 mi, 1000 ft/2 mi, 500 ft/1 mi, 200 ft/1/2 mi.

*See TESS Study, Appendix F for other and more specific values.

Figure B-2

CONDS PLANNING PHASE (TIMES FOR ILLUSTRATION ONLY)

Weather Support Element	D-30	D-15	D-5	D-1	D-1	D
Brigade Wx Element						c
Division Wx Element			ab 1,2,3,4,5	db 1,2,3,4,5	db 1,2,3,4,5	d 6
Corp Wx Element	a 1,2,3,4,5	b 1,2,3,4,5	b 6			
BFU/Theater Wx Ele						ab
AFBWC	a	ab	ab	b	b	b

Weather Support ResponsibilitiesOperational Consideration

- | | |
|---------------------|----------------------------|
| a. Centralized CMSI | 1. Time of day/month |
| b. Centralized FMSI | 2. Location, terrain, etc. |
| c. Observations | 3. Type of unit/equipment |
| d. Local FMSI | 4. Tactics/threat |
| e. Local CMSI | 5. OPLAN |
| | 6. OPORD |

EMPLOYMENT PHASE (TIMES FOR ILLUSTRATION ONLY)

Weather Support Element	D-Day H-Hour	24 Hr	48 Hr	72 Hr	3 Day	7 Day	30 Day
Brigade Wx Ele	c						
Division Wx Ele	dc 1,2,3,4,5,6	dc	dc	dc	dc		
Corps Wx Ele		dc 1,2,3,4,5	b 1,2,3,4,5				
BFU/ Theater Wx Ele		bd	bd	bd			
AFGWC		ab	ab	ab	ab	ab	ab

Appendix C*

LIST OF DATA POINTS USED IN REFORGER 76

GRID PT.	ROW 1	GRID PT.	ROW 5
1	51°00'N - 08°30'E	29	50°00'N - 08°00'E
2	51°00'N - 09°00'E	30	50°00'N - 08°30'E
3	51°00'N - 09°15'E	31	50°00'N - 08°45'E
4	51°00'N - 09°30'E	32	50°00'N - 09°00'E
5	51°00'N - 09°45'E	33	50°00'N - 09°15'E
6	51°00'N - 10°00'E	34	50°00'N - 09°30'E
		35	50°00'N - 09°45'E
		36	50°00'N - 10°00'E
GRID PT.	ROW 2	37	50°00'N - 10°15'E
7	50°45'N - 08°30'E	38	50°00'N - 10°30'E
8	50°45'N - 08°45'E	39	50°00'N - 11°00'E
9	50°45'N - 09°00'E		
10	50°45'N - 09°15'E	GRID PT.	ROW 6
11	50°45'N - 09°30'E	40	49°45'N - 08°30'E
12	50°45'N - 09°45'E	41	49°45'N - 08°45'E
13	50°45'N - 10°00'E	42	49°45'N - 09°00'E
		43	49°45'N - 09°15'E
GRID PT.	ROW 3	44	49°45'N - 09°30'E
14	50°30'N - 08°30'E	45	49°45'N - 09°45'E
15	50°30'N - 08°45'E	46	49°45'N - 10°00'E
16	50°30'N - 09°00'E	47	49°45'N - 10°15'E
17	50°30'N - 09°15'E	48	49°45'N - 10°30'E
18	50°30'N - 09°30'E	49	49°45'N - 11°00'E
19	50°30'N - 09°45'E	50	49°45'N - 11°15'E
20	50°30'N - 10°00'E	51	49°45'N - 11°30'E
		52	49°45'N - 11°45'E
GRID PT.		53	49°45'N - 12°00'E
GRID PT.	ROW 4		
21	50°15'N - 08°45'E	GRID PT.	ROW 7
22	50°15'N - 09°00'E	54	49°30'N - 08°00'E
23	50°15'N - 09°15'E	55	49°30'N - 08°30'E
24	50°15'N - 09°30'E	56	49°30'N - 08°45'E
25	50°15'N - 09°45'E	57	49°30'N - 09°00'E
26	50°15'N - 10°00'E	58	49°30'N - 09°15'E
27	50°15'N - 10°15'E	59	49°30'N - 09°30'E
28	50°15'N - 10°30'E	60	49°30'N - 09°45'E
		61	49°30'N - 10°00'E
		62	49°30'N - 10°30'E
		63	49°30'N - 10°45'E
		64	49°30'N - 11°00'E
		65	49°30'N - 11°15'E
		66	49°30'N - 11°30'E
		67	49°30'N - 11°45'E
		68	49°30'N - 12°00'E

*This appendix was an attachment to Reference 2.

GRID PT.

69
70
71
72
73
74
75
76
77
78
79

ROW 8

49°15'N - 09°30'E
49°15'N - 10°00'E
49°15'N - 10°15'E
49°15'N - 10°30'E
49°15'N - 10°45'E
49°15'N - 11°00'E
49°15'N - 11°15'E
49°15'N - 11°30'E
49°15'N - 11°45'E
49°15'N - 12°00'E
49°15'N - 12°15'E

GRID PT.

95
96
97
98
99
100
101
102
103
104
105
106

ROW 10

48°45'N - 09°30'E
48°45'N - 09°45'E
48°45'N - 10°00'E
48°45'N - 10°15'E
48°45'N - 10°30'E
48°45'N - 10°45'E
48°45'N - 11°00'E
48°45'N - 11°15'E
48°45'N - 11°30'E
48°45'N - 11°45'E
48°45'N - 12°00'E
48°45'N - 12°15'E

GRID PT.

80
81
82
83
84
85
86
87
88
89
90
91
92
93
94

ROW 9

49°00'N - 08°00'E
49°00'N - 08°30'E
49°00'N - 09°00'E
49°00'N - 09°30'E
49°00'N - 09°45'E
49°00'N - 10°00'E
49°00'N - 10°15'E
49°00'N - 10°30'E
49°00'N - 10°45'E
49°00'N - 11°00'E
49°00'N - 11°15'E
49°00'N - 11°30'E
49°00'N - 11°45'E
49°00'N - 12°00'E
49°00'N - 12°15'E

GRID PT.

107
108
109
110
111
112
113
114

ROW 11

48°30'N - 09°00'E
48°30'N - 09°30'E
48°30'N - 10°00'E
48°30'N - 10°15'E
48°30'N - 10°30'E
48°30'N - 11°00'E
48°30'N - 11°30'E
48°30'N - 12°00'E

Appendix D*

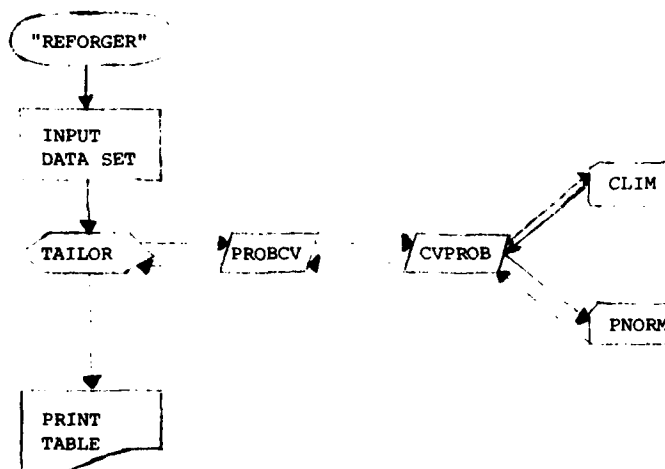
SIMULATION PROGRAMS

1. Program "REFORGER" - Stepping Simulation Model.

a. The overall program structure is as follows:

Main Program: "REFORGER"

Function Subroutines: TAILOR, PROBCV, CVPROB, PNORM, CLIM



The input data (integer format) provided the program REFORGER are:

Month of year

Mission type

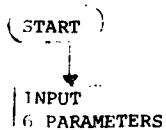
Time (GMT)

Forecast length-hours

Grid points of interest

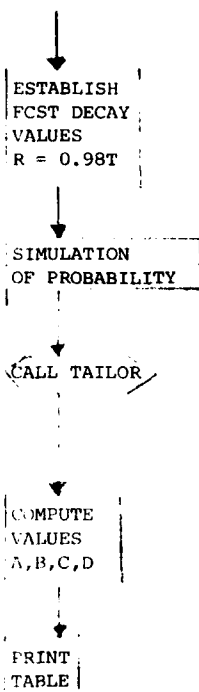
The program is established to execute on the ARPA system at USAFETAC and the input data set was provided the program via an interactive CRT. The SMSI tables produced by the program REFORGER were put into a storage file and then printed on a high speed printer.

b. The structure of the main program is as follows:



*** MON: Month (1-12)
 MISSION: Mission type (1-7)
 ITOD: Time of day (00-23)
 NN: Forecast length (1-# HRS)
 IGPS: Starting grid point (1-114)
 IGPE: Ending grid point (1-114)

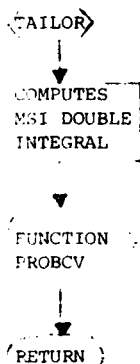
*This appendix extracted from Reference 14.



*** Function Parameters:

MISSION: Mission type
 PM: Mean Predictor (*) (*) Equivalent normal value
 D: Deviate (*)
 R: Correlation Coefficient
 IGRID: Grid-point number
 ITOD: Time of day
 MON: Month

c. The structure of the function subroutine TAILOR is as follows:



$$E = E + P + (C(I), V + (J) +) * WTCV + (I, J)$$

(D-1)

*** Function parameters:

MISSION: Mission type
 CIG: Ceiling value (10^2 feet)
 I: I-counter
 VIS: Visibility value (10^3 meters)
 J: J-counter
 PM: Mean Predictor (*)
 D: Deviate (*)
 ITOD: Time of day
 MON: Month

(*equivalent normal value)

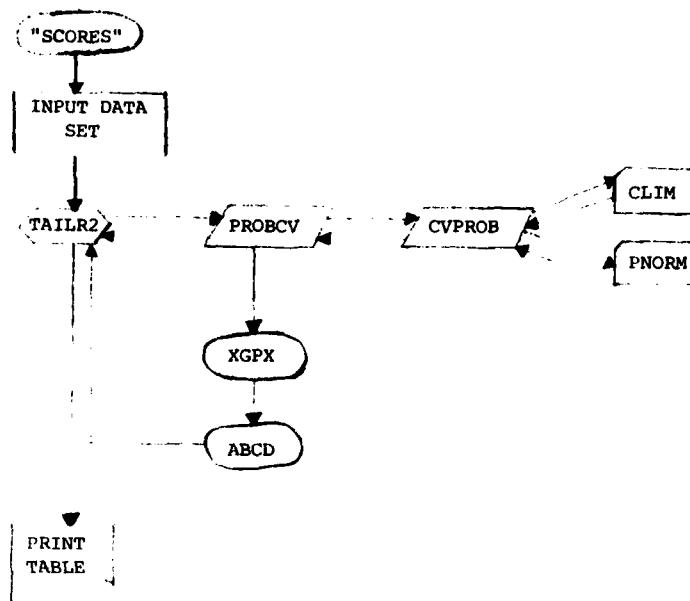
The function is used to compute mission success indicators as a function of the probability of ceiling, visibility and ceiling/visibility and the weighting factor for each mission type.

1. Program "SCOPES" - Continuous Category Simulation.

a. The overall program structure is as follows:

Main Program: REFORGER

Function Subroutines: TAILR2, PROBCV, CVPROB, CLIM, PNORM, XGPX, ABCD

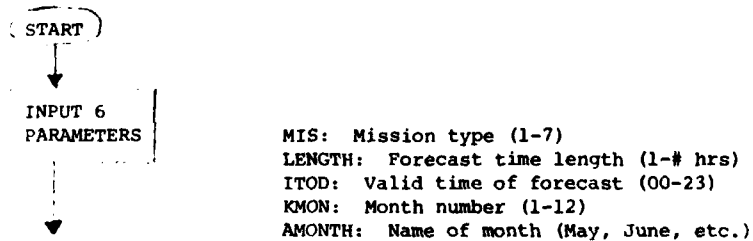


The input data (integer format) provided the program SCORES are:

Mission type
 Forecast length-hours
 Valid time of forecast (GMT)
 Month of the year
 Name of the month (alphanumeric format)
 Grid-point increment

The program SCORES integrated from grid point number 1 to 114 using the grid point increment as specified. Additionally, for each mission there was a specified maximum critical probability which limited the number of lines printed for each SMSI table.

b. The structure of the main program is as follows:

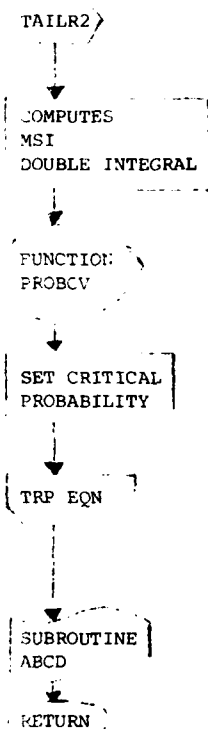




*** Function Parameters

Mission type
 Mean predictor (END)
 Deviate (END)
 Grid-point number
 Time of day
 Month number
 Critical probability
 Forecast length

c. The structure of the function subroutine TAILOR is as follows:



$$\Sigma + \Sigma + P(C(I), V(J)) * WTCV + (I, J)$$

(D-2)

*** Function Parameters

MISSION: Mission type
 CIG: Ceiling value (10^2 feet)

I: I-counter
 VIS: Visibility value (10^3 meters)
 PM: Mean predictor (END)
 IGRID: Grid-point number
 ITOD: Time of day
 MON: Month

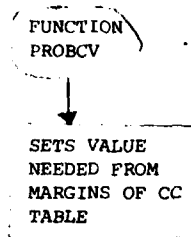
*** Subroutine Parameters

..
 XI: X (END)
 YHAT: Y (END)
 R: Correlation coefficient
 WGT: Mission weight
 X: CLIMO probability
 A: Contingency table value A
 B: Contingency table value B
 C: Contingency table value C
 D: Contingency table value D
 APRIM: A * WGT

3. Program Function Subroutines:

a. This section contains a flowchart and calling parameters of functions used by the "REFORGER" and "SCORES" programs. The relative location of each function within the logic flow of producing SMSI's can be found in Sections 1 and 2. The functions common to both the SMSI programs are PROBCV, CVPROB, CLIM and PNORM. The function unique to "REFORGER" is TAILOR and to "SCORES" is TAILR2. TAILR2 contains a minor modification of TAILOR to adjust mission weighting. The program "SCORES" also contains the additional functions XGPX, ABCD, and BNINT.

b. The structure of the function subroutine PROBCV is as follows:

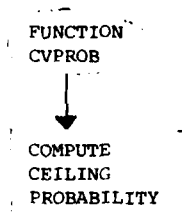


*** Function Parameters

CIG (Counter, Mission): Ceiling value
 VIS (Counter, Mission): Visibility value
 PM: Mean predictor (*)
 D: Deviate (*)
 IGRID: Grid-point number
 ITOD: Time of day
 MON: Month
 (* equivalent normal value)

The function PROBCV is used to calculate the actual probability for the ceiling and visibility event considered.

c. The structure of the function subroutine CVPROB is as follows:

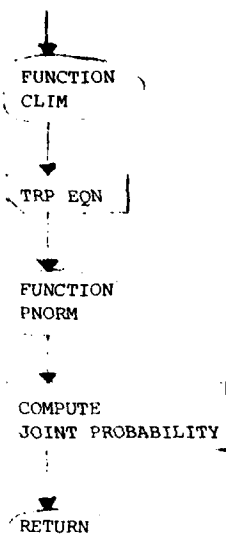


*** Function Parameters

KIND: Weather type
 IGRID: Grid-point number
 ITIP: Ceiling or visibility category
 ITOD: Time of day
 MON: Month

*** Function Parameters

PHTC: Equivalent normal value of probability



This function computes the cumulative probability for the ceiling, visibility, and grid-point number as requested by "TAILOR" or "TAILR2." The joint probability of ceiling and visibility is approximated by

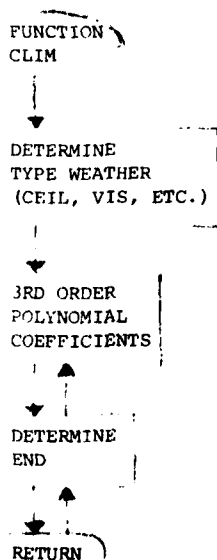
$$\begin{aligned} \text{CVPROD} &= 0.7 * P(\text{cig}) * P(\text{vis}) \\ &+ 0.3 * \min(P(\text{cig}), P(\text{vis})) \end{aligned} \quad (\text{D-3})$$

The TRP equation,

$$P = \frac{\bar{Y} - R\bar{x}}{\text{SQRT}(1-R^2)} \quad (\text{D-4})$$

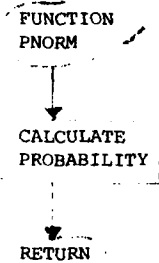
is used to calculate the END of ceiling or visibility probability as a function of correlation at time t and climatology of the event.

d. The structure of the function subroutine CLIM is as follows:



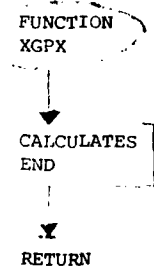
The function subroutine CLIM returns the equivalent normal deviate (END) of the value generated for the ceiling and visibility variable. There are two basic steps in obtaining the END. First, a regression equation is used to generate the coefficients for the cubic equation that produces the END. The coefficients, a,b,c, and d are then inserted into the third-order polynomial and the resulting value is the END for that grid point.

e. The structure of the function subroutine PNORM is as follows:



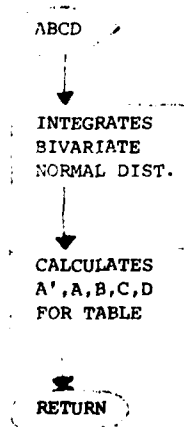
The function returns the normalized cumulative probability value for supplied equivalent normal deviate (END). The equation used is from Abramowitz (ed. 1965) Handbook of Mathematical Function, Eq: 26.2.18.

f. The structure of the function subroutine XGPX is as follows:



The function returns the Equivalent Normal Deviate (END) for a supplied cumulative probability value. The equation used is from Abramowitz (Ed. 1965) Handbook of Mathematical Functions, Eq: 26.2.23.

g. The structure of the function subroutine ABCD is as follows:



*** Function BNINT Parameters

XHAT: END value
YHAT: END value

R: Correlation coefficient

This subroutine determines the value of A,B,C, and D which are printed out and represent the regions of the contingency table. A' represents the probability of success weighted by the weapon system probability of hitting the target.

```

A' = (A)*(Weapon system weight)

A = Bivariate normal probability between X and Y (BNINT)

B = Y - A

C = PNORM (X) - A = X-A

D = 1.0 - X - C

Y = Unconditional climatological probability

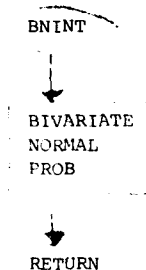
X = Unconditional probability obtained from TRP equation

"
Y = END of probability Y
"
X = END of probability X

```

Output from "SCORES" ABCD subroutine is provided in Table D-2.

h. The structure of the function subroutine BNINT is as follows:



The function BNINT integrates the Bivariate normal distribution given two probabilities and the correlation coefficient R. It is an interactive procedure utilizing a series of equations which approximates the area between the two marginal probabilities.

4. Program Samples - Input and Output.

a. The input parameters required to execute the SMSI program on the ARPA terminal requires the following commands:

<u>Terminal CRT</u>	<u>User Supplied Information</u>
"input month, mission, time of day and forecast length - 4I2"	REFRGR (SCORES)
"input first and last grid points desired - 2I3"	08070012
	002004

As program works through grid points, the following messages appear on terminal CRT)

```

"working on grid point 2"
"working on grid point 3"
"working on grid point 4"
"end of job - data written to diskfile rigr.out"

```

EXIT

"C" (Control C)

@

b. The program has now executed and has output data to a file that can now be printed at USAFETAC. There are two options as to how data files can be transferred. Option 1 is to have the output SMSI files sent directly to the printer. This is not recommended when the output file is larger than 100 pages as time to print data can be excessive. Option 2 is to have the output files copied on a 7-track tape at USAFETAC. This method is considerably faster than the direct to printer method and once a tape is built, the IBM 360/44 can be used to print the tape. The commands for generating hard copy of SMSI information are:

Terminal CRT

User

@

write. from. file:

(ETAC) WRTFIL

RFGR.OUT; 1 (SCORES.OUT; 1)

'P (control P)

Printing page __ of __ pages __% of file printed

write.from.file:

'C (control c)

At this point output file is in hard copy. The data shown on the following page is an example of the data output to support REFORGER 76. Note that the critical probabilities can include values 0.05 through 0.95 even though not shown on output.

TABLE D-1: Example SMSI Output (REFORGER)

MISSION: CLOSE AIR SUPPORT
 FORECAST TIME LENGTH = 12 VALID AT 1200Z
 MONTH = SEPTEMBER
 PRODUCED BY USAFETAC

GRID POINT	CRITICAL PROBABILITY	MISSION EXEC WITH SUCCESS	MISSION NOT EXEC WOULD HAVE SUCCEEDED	MISSION EXEC DID NOT SUCCEED	MISSION NOT EXEC AND WOULD NOT HAVE SUCCEEDED
1	.050	.117	.010	.495	.378
1	.100	.104	.023	.337	.537
1	.150	.081	.036	.245	.629
1	.200	.075	.052	.169	.705
1	.250	.061	.065	.122	.752
1	.300	.042	.084	.072	.802
1	.350	.027	.099	.042	.832
1	.400	.013	.113	.018	.856
1	.450	.000	.126	.000	.874
1	.500	.000	.126	.000	.874

MISSION: CLOSE AIR SUPPORT
 FORECAST TIME LENGTH = 12 VALID AT 1200Z
 MONTH = SEPTEMBER
 PRODUCED BY USAFETAC

GRID POINT	CRITICAL PROBABILITY	MISSION EXEC WITH SUCCESS	MISSION NOT EXEC WOULD HAVE SUCCEEDED	MISSION EXEC DID NOT SUCCEED	MISSION NOT EXEC AND WOULD NOT HAVE SUCCEEDED
2	.050	.034	.019	.213	.735
2	.100	.026	.027	.110	.837
2	.150	.019	.033	.067	.881
2	.200	.013	.040	.037	.910
2	.250	.007	.045	.018	.930
2	.300	.004	.049	.007	.940
2	.350	.000	.053	.000	.947
2	.400	.000	.053	.000	.947
2	.450	.000	.053	.000	.947
2	.500	.000	.053	.000	.947

TABLE D-2: EXAMPLE SMSI PRINTOUT (SCORES)

MISSION: TOW-2
 FORECAST TIME LENGTH = 12 VALID AT 1200Z
 MONTH = SEPTEMBER
 PRODUCED BY USAFETAC

GRID POINT	A	A'	B	C	D
	MISSION EXEC WEATHER OK	MISSION EXEC WITH SUCCESS	MISSION NOT EXEC COULD HAVE GONE	MISSION EXEC WX NO GOOD	MISSION NOT EXEC AND WOULD NOT HAVE SUCCEEDED
1	.050	.619	.001	.135	.005
1	.100	.618	.001	.128	.012
1	.150	.617	.003	.121	.019
1	.200	.616	.005	.113	.027
1	.300	.613	.009	.104	.036
1	.400	.608	.015	.094	.046
1	.500	.602	.024	.084	.056
1	.600	.594	.036	.073	.067
1	.700	.582	.052	.062	.078
1	.800	.565	.075	.050	.090
1	.900	.542	.107	.038	.102
1	.950	.507	.156	.026	.114
1	.975	.449	.236	.014	.126
1	.990	.319	.417	.003	.137

NOTE: Column A is the probability of mission favorable weather.
 Column A' is the MSI. It is derived by multiplying the values in Column A by 0.72, the kill factor for the TOW-2 system in perfect weather.

